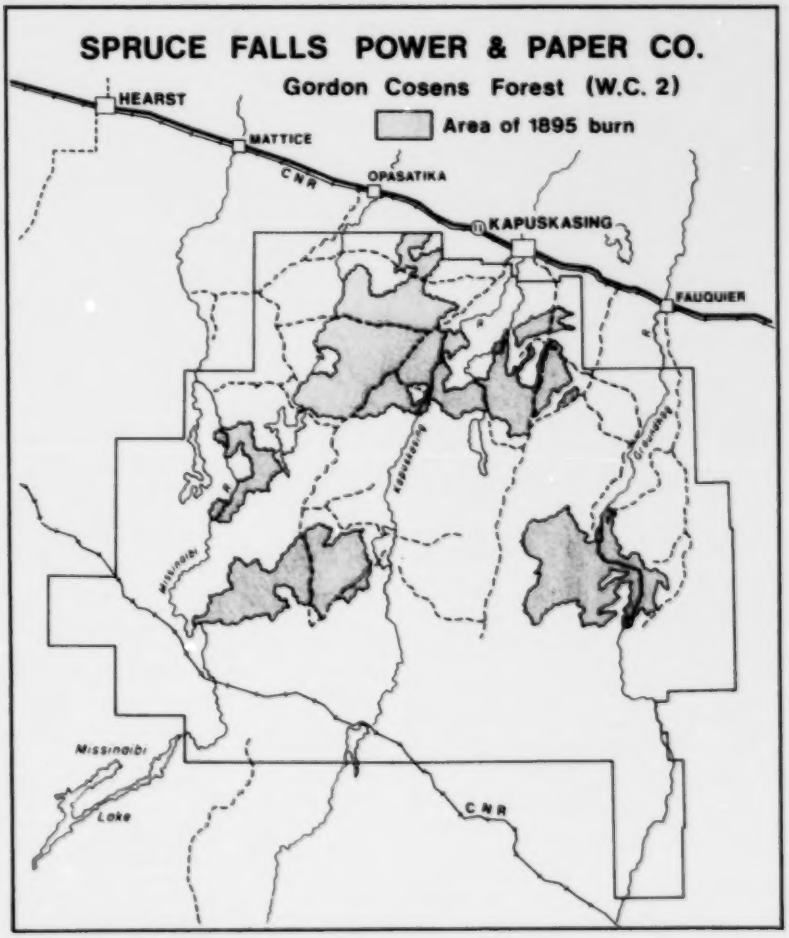
Science and Technology Series, Volume 2

Forest Management And Access: Harvest Allocation Options And Their Impact On Road Expenditures

A Simulation Study



Ontario
Ministry of
Natural
Resources

FOREWORD

For large areas in the boreal forest region of Ontario, the first major activity in forest management is the development of roads to provide access to timber for harvesting and subsequent regeneration and maintenance or tending operations.

Decisions as to the location and extent of the roads to be constructed in any particular planning period are governed by several factors, a major one being the nature and location of stand of merchantable timber of the desired species. The boreal forests are largely of natural fire origin, therefore the extent and distribution of stands of different age classes is typically non-uniform and highly imbalanced.

A basic tenet in forest management is to harvest the oldest stands of merchantable and rotation age first. While this may be satisfactory in a regulated forest of balanced age class distribution which has its primary access developed, the 'opening up' of a forest of the type generally encountered in northern Ontario presents major difficulties.

Not only does it mean that the oldest stands are often several decades past their rotation age i.e. they are overmature, and therefore have lower volumes and higher incidence of defect, but it also necessitates by-passing stands of higher volumes and quality which are still of rotation age i.e. mature. The major costs of road construction and subsequent maintenance are thus increased greatly by strict adherence to allocating only the oldest stands for harvesting.

The nature of the criteria used to establish harvesting priorities and their degree therefore can have a dramatic effect on road expenditures and also on the short, medium and long-term nature and cost of wood supply.

This study was undertaken on a large forest area in northern Ontario to test the application of different harvest options and their effects on wood supply and road expenditures. It should be emphasized that the major objective was to develop an analytical 'model' that could have more general application and therefore the comparisons in this study of costs are relative and not absolute.

K. A. Armson, R.P.F.
Provincial Forester

PREFACE

The relationship between access construction and forest management has been poorly understood. Critics of the government's access policy have often portrayed capital construction and forest management as competing and conflicting demands on the public purse.

At the same time following a recent audit of Ontario's forest management (Baskerville, 1986), the province has been reviewing the implications of its harvest allocation rules not only for access construction but also in terms of long-term wood supply and silvicultural objectives for the future forest.

This study was undertaken in the winter of 1985 with a view to modelling the relationships between three factors - forest stand characteristics, harvest allocation rules, and road construction and maintenance. The intended audiences are government decision makers who must understand forest management and its fiscal implications in order to make resource policy and the growing community of forest economists in Canada who are looking for new ways to tackle practical forest management issues.

The study is designed to reflect the government's view of forest management and capital spending. Therefore government costs and assessments of the benefits of forest production are used. Although the author benefitted from the gracious cooperation of the staff of Spruce Falls Power and Paper Company (whose Gordon Cosens Forest agreement area served as the base of the study), the views expressed are solely those of the author.

This work is of necessity preliminary in nature. The model demonstrates a prospective methodology for examining some forest management - capital support combinations. Because it is a model, the complexities of the real situation have been simplified and many untested assumptions have been made.

As a simulation model the work is not intended to prove the superiority of one allocation strategy over another. The point is simply to demonstrate relationships. In fact, one key understanding that emerges is that no one allocation strategy should be applied everywhere. Each unit must be managed and roaded according to the dictates of the forest stand dynamics and local opportunities and constraints. Equally no simple roading strategy can be designed without limiting the forest management options.

There are no simplistic answers in forest management. Increasingly we are compelled to draw on modeling and decision analysis tools to assist us in making choices in a complex economic and biological environment. This paper is one step in that direction.

Jeremy Williams

EXECUTIVE SUMMARY

Since 1980, when the first Forest Management Agreement (FMA) was signed, forest companies, as agreement holders have assumed responsibilities for forest management, particularly the integration of harvesting and regeneration activities. One result has been increased expenditures on road access and a wider application of the "oldest first" as a harvest allocation rule. The implications of widespread application of this rule, especially in forest area with a preponderance of old growth timber have not been quantified.

The objective of this study therefore, was to develop a deeper understanding of the relationships that exist between the choice of a harvest allocation rule, stand characteristics, and road construction and maintenance costs. For an an actual forest area of sq. km, a series of simulations were run under four different harvest allocation principles. The allocation rules examined were: 1) oldest first, the current policy; ii) minimum road extension; iii) harvesting preferred sites, i.e. higher timber productivity; iv) harvesting by opportunity cost, which is the sum of the direct and indirect costs resulting from a delay of harvest.

The simulation results clearly show that harvest Characteristics, road construction, and the forest's biological characteristics are interrelated and that one element cannot be adjusted without affecting the other two. The rule used to allocate stands for harvest affects all three elements and just as importantly, its performance is affected by the latter two. The biological characteristics of the forest help to determine the allocation rule that will best achieve policy goals. The access network affects the ability to carry out the allocation rule and the location of the

harvest and so it too has long-term implications for the forest structure. The forest and the harvest allocation (rules) are mutually dependent.

Procedure

The study was done by adapting the Ontario Wood Supply and Forest Planning model (OWOSFOP) to run on a stand-by-stand basis and simulate road construction and the operation of four generic harvest allocation rules for a period of sixty years. The specific properties of each allocation rule were modified by adjusting key parameters, so that a range of outcomes was produced for each rule. A forest management area was selected that has large volumes of overmature timber further from the mill than many rotation-aged stands. All simulations were performed on the sample study area.

Forest Resources Inventory (FRI) data were adapted (in consultation with company and local Ministry foresters) to categorize stands by conifer volume, yield behaviour and management type. There were two major stand classes, designated as upland and lowland. Stands on upland sites collapse i.e. deteriorate rapidly at younger ages than lowland stands and are more prone to regenerate to hardwoods.

In each iteration, the revised OWOSFOP model evaluated whether the desired harvest could be obtained from accessible stands, extended current roads as necessary, made the harvest and returned the cutover to the appropriate regeneration category. The harvest level was set equal to the maximum allowable depletion (MAD) and was updated every five years.

To simulate the oldest first allocation, accessible stands were ranked by age and those above a certain user-designated age were considered "oldest" stands and targetted for harvest. If a prescribed proportion of the MAD could not be met from these stands, roads were extended until this condition was satisfied.

The minimum road extension scenario was exactly that - roads were extended only as much as required to obtain the MAD from stands older than 80 years.

A preferred site was defined as a site which would yield a high discounted net return under management. A high conifer volume yield, rapid growth rate, and low management costs were factors which tended to make a site more valuable. A fixed proportion of the MAD was taken from stands on preferred sites while the remainder of the cut was taken from non-preferred stands on an oldest first basis.

The opportunity cost scenario was simulated by taking a user-prescribed percentage of the MAD from stands with a high opportunity cost. The opportunity cost is the sum of the direct and indirect effects of not doing something - in this study it is the cost of not harvesting a hectare of forest. Target stands had high conifer volumes, a rapid rate of volume loss, or a combination of both attributes. Overall, the effect was to set a harvest age range covering the ages of maximum volume and most rapid collapse, write off older stands, and leave younger ones. The non-target portion of the MAD was obtained on an oldest first basis.

Comparison of Scenarios

In this investigation, a representative sample of simulations was performed. The harvests obtained under the four principles were evaluated in terms of total volume and the behaviour of the annual timber flow over a 60-year period. Total volume did not vary appreciably between scenarios. Slight decreases were observed as the oldest first and preferred sites scenarios were followed more stringently and somewhat higher volumes were obtained when the opportunity cost scenario was followed more intensively. In this particular sample management unit, the large area of overmature forest led to declining annual harvest volumes during the first thirty years of all simulations. This was unavoidable but it was mitigated under the minimum roads and opportunity cost rules, which gave a more gradual decline that was at a minimum with a larger volume than achieved under oldest first and preferred sites. The most volatile annual harvest volumes were also obtained under the oldest first and preferred sites scenarios.

When the oldest first, preferred sites, and opportunity cost scenarios were simulated, road costs increased as harvest selection criteria became more exacting. The decision to allocate the harvest more selectively is the reason that roading costs have risen over the last eight years. A corollary of this conclusion is that road costs cannot be constrained without sacrificing management options.

The total length of roads constructed did not vary much from scenario to scenario; virtually the entire management unit was accessible by the end of each simulation. The chief difference was in the timing of expenditures.

When management became more selective or a certain group of stands were relied upon to provide a greater proportion of the harvest, greater access was required and road building had to be accelerated. The discounted road cost per cubic metre harvested relates the total discounted road expenditure to the total harvest yielded under each scenario. In the simulations, this statistic generally rose as harvest allocations became more selective.

The harvest rule also influences the biological characteristics of the forest. This relationship is of prime interest in the preferred sites case since the stands selected for harvest now are expected to yield larger volumes of conifers in the next rotation. Also, the extent of harvesting on each site type differed between allocation scenarios. For example, the percentage of lowland cut varied by as much as 20%.

The major conclusion of this study is that the two major partners in forest management - government and industry - must make higher front-end investments in access where selective management is required. Greater access promotes efforts to stretch the existing supply of timber and take advantage of greater storability of wood on some sites, as well as providing enhanced management of the new forest.

A secondary implication arising from this study is that province-wide management policies cannot be set too stringently, since the performance of an allocation rule is so dependent on the basic characteristics of a forest in particular its structure and age class distribution. The same rule will achieve different results in different management units and, equally, in the same management unit at different times.

FOREST MANAGEMENT AND ACCESS: HARVEST ALLOCATION OPTIONS AND THEIR IMPACT ON ROAD EXPENDITURES

INTRODUCTION

Many Ontario forest management units have marked imbalances in the age class distribution of commercial species. In most cases, there is a preponderance of mature and overmature stands. The Ontario Ministry of Natural Resources' current harvest policy is to direct cutting to the oldest stands, so that they may be felled before they lose their commercial viability. This policy was introduced with the advent of the Forest Management Agreement Act in 1979, which provided the legal framework for the agreements under which the Ministry and individual companies share the work of performing a broad range of forest management activities. (These agreements are known as Forest Management Agreements or FMA's[1].)

As more FMA's were signed, road building expenditures increased above traditional levels and show no indication of declining in the near future. Therefore, this study was initiated to determine if road costs could be constrained without adversely affecting other forest management objectives. At the same time, it was recognized that this study would shed light on the interaction between management goals and different harvest allocation principles.

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[1] Forest Management Agreement (FMA): a contractual agreement between the OMNR and a company under the Crown Timber Act to provide for a continuous supply of forest products from the designated lands for the wood-processing plants of the company and to ensure that the forests on such lands are harvested and regenerated to produce successive crops of timber on a sustained-yield basis (OMNR 1986).

A central management objective has been to obtain a sustained yield of timber by creating a more regulated forest (i.e., a more uniform age class distribution no older than rotation age). However, other management goals enter into consideration as each individual management unit is considered. Examples of some auxiliary goals that are of widespread relevance in Ontario include stretching the existing wood supply so as to alleviate anticipated gaps in the wood supply and intensifying management on valuable sites close to the mill. Other objectives may be prominent in certain units.

The scope of this study was more limited. By means of simulations, road construction and maintenance costs and timber harvests were modelled under four different harvest allocation rules. The four rules examined were: i) oldest first; ii) minimum road extension; iii) harvesting preferred sites[1]; and iv) harvesting to minimize opportunity costs. The forest characteristics of interest were the overall volume and the distribution of wood supply over time.

The simulation model used in this study was an adaptation of the Ontario Wood Supply and Forest Planning model (OWOSFOP) used by the Ministry to calculate the maximum allowable depletion (MAD)[2] for

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[1] Preferred Sites - a forest site which will yield a higher discounted net return under management. In this study higher conifer productivity as indicated by forest inventory site class and soil drainage were used as the main determinants for a preferred site.

[2] MAD - The calculated amount of area from which timber may be depleted over the five-year term of a Timber Management Plan by any means, including harvesting, fire, insects, disease, inoperability, or because of the allocation of the area to other uses to fulfil the objectives of management (OMNR, 1986).

each FMA. Using this model one can examine the general behaviour of various harvest allocation rules and determine how a harvest rule, the forest yield behaviour and the site and age class distribution of the forest affect timber flow, total timber yield and road expenditures. The timber flow is perhaps the most important outcome. Due to the age structure imbalances in many management units, there is the probability of significant reductions of rotation-aged wood once the existing overmature stands have been cut or deteriorate. For this reason, the results of each harvest allocation scenario were assessed over a 60-year period.

To calibrate the potential costs and benefits of each harvest scenario, reference is made to a specific management unit - its existing road structure, the cost of road building, the size of the maximum allowable depletion (MAD) and the size and location of stands of various site classes, age classes and species. All simulations were conducted on management unit data.

The Study Unit And Its Road Network

The test area is a large management unit in the Ontario clay belt, currently licensed as an FMA. The area was sq. km in extent. The terrain consists of approximately 65% lowland and swamp with organic soils and 35% upland sites with mineral soils. The major commercial species are black spruce (Picea mariana Mill, BSP) which, together with white spruce (Picea glauca (Moench) Voss) and balsam fir (Abies balsamea L.), are principally used to produce lumber and pulp. These three species constitute about 90% of the wood volume removed to

different processing facilities. It is forecast that between 1983 and 1988, 75% of the maximum allowable depletion will come from the spruce and balsam fir working groups[1].

Three rivers run through the management unit along a north-south axis. They impose limitations on the design of the road network, since permanent crossings are expensive to build. The rivers are large enough to permit timber to be driven to the mills and over one-third of the cut is brought to the mill this way, with substantial cost savings. Another significant feature of the unit is that a large part of it was burnt in 1895 and is now commercially harvestable. Portions of the burn area are presently accessible, although a complete road access network has yet to be built.

Historically, the company has constructed roads according to the specifications of primary roads, although some secondary roads are now being built. Tertiary roads are ignored in this study. They do not have significant construction costs.

Secondary roads are presumed to be kept open for five years after the last harvest cut along that road. Five years of maintenance is required to keep the road open for site preparation, planting, tending, and assessment. Thereafter, it is assumed to be abandoned.

Most primary roads are permanent, but primary spur roads which do not lead to a body of water or join another road are assumed to be abandoned. For those which are to be abandoned, a five-year

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[1] Working Group: an inventory aggregation for management purposes; an aggregation of stands, including potential forest areas assigned to this category, having the same predominant species, and managed under the same rotation and broad silvicultural system (OMNR, 1986).

interval is again allowed between the last harvest cut and abandonment.

There are third-party[1] operators in this management area who haul year round. In this type of operation, main roads must pass within 1.3 kilometers of a stand for it to be considered accessible. In this unit, third-party operators construct a much higher proportion of secondary roads than the Agreement holder (FMA) but since the duration of these operations is less definite, they are assumed to have a minimal impact on the overall road network.

Stand Classification

To make the simulations as accurate as possible, it was necessary to predict the growth of present stands and the development of the regenerated forest. Yield tables serve the former purpose but unfortunately, they are not accurate predictors of stand volumes in the declining and post-decline stages of a stand's history. Little information exists that predicts future stand development on the basis of present stands in the context of a managed forest.

The forest resources inventory (F.R.I.) system is useful for providing estimates of current stand volumes and, for some stands, its link with site yield tables (Plonski, 1960) allows for accurate yield predictions. Unfortunately, spruce stands are especially variable, at

[1] A Third-party operator is one who does not sign a cutting agreement directly with OMNR, but does so indirectly through an existing licensee. A third-party operator generally harvests timber that the principle license holder would otherwise declare as surplus. Third-party agreements generally run for one or two years.

least in the sample management unit. Part of the variability stems from growth differences between upland and lowland sites. Smith (1983) constructed a set of volume tables for spruce in this area and showed that spruce frequently does not behave according to Plonski's tables, especially in a stand's declining years.

The current inventory system was the only stand information that was in a format suitable for use in a stand-by-stand simulation project but an inventory is not designed to provide all of the information that was needed for this project. Additional information was required. A stand classification system was developed based on the cover types listed in the F.R.I, the ground rules[1] for the management unit, and most importantly, the experience of Ministry and company foresters. This system allowed for stand projection and linked future stands with present ones.

Existing stands were separated into lowland, upland and jack pine (Pinus banksiana Lamb.) site types on the basis of their cover type. Stands with 90 - 100 per cent softwood were assigned to the lowland category and stands with 20 - 100% hardwood were assigned to the upland category. Exceptions occurred when stands had more than 50% jack pine present - they were assigned to the jack pine category, which subsequently turned out to be of minor significance. One important assumption that was made was that all existing stands had the characteristics of unmanaged stands natural forest, which they were.

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[1]Ground Rules: These provide specifications, standards, and other instructions (mostly silvicultural) to direct management on management unit areas for a term concurrent with the operating period of the timber management plan (OMNR, 1986).

Upland and lowland stands were further divided according to the management intensity that would be applied to the suceeding stand. At this stage, upland stands were handled differently from lowland stands.

When upland stands were cut, they were assigned to a regeneration class on the basis of the present cover type. There were three regeneration classes: unmanaged, mixed wood and spruce (listed from low to high management intensity). More intensive management was assumed to raise the proportion of spruce on a site and make it available sooner. It is very difficult and costly to remove the white birch (Betula papyrifera Marsh) and poplar (Populus Spp. L.) components of a stand. One can expect to find roughly the same percentage of these hardwoods in the regeneration as in the original stand. In essence, the current cover type was assumed to determine the level of management intensity; which in turn determined the species composition of the future stand. Stands having 100 per cent white birch or poplar were left unmanaged in this simulation, since it is rarely worth trying to introduce a significant spruce component. Stands with a 70-90 per cent hardwood component were managed at a moderate intensity and regenerated to mixed wood, whereas stands with 20-60% hardwood were brought back to predominantly softwood stands through intensive management.

Factors such as the depth to the water table, depth of organic soil and type of peat influence the intensity of management on regenerating lowland sites. These site factors are not given by the Forest Resources Inventory (F.R.I.) Hence, an accurate assignment of

regeneration prescriptions to current lowland stands was not possible. But it was undesirable to put all of the lowland forest into one management class. As a result, lowland stands of F.R.I. site classes X and 1 were assumed to receive intensive management and those in site classes 2 and 3, extensive management.

These criteria resulted in the management unit being sub-divided as follows:

Table 1

Area in each of the six site types

		Area (ha.)	% Total Area
Upland:	Unmanaged	44,515	4.8
	Mixed Wood	106,582	11.5
	Spruce	209,986	22.7
	Total	361,083	39.2
Lowland:	Unmanaged	279,599	30.2
	Managed	268,122	28.9
	Total	547,721	59.1
Jack Pine:		17,641	1.9
	Total	926,445	100.0

The decision to move away from the F.R.I. site class system to a stand type system is of interest. There were four main reasons. One is that current harvest yields bear little correlation to the F.R.I. site class, primarily because most stands being cut now are so old that their volume has fallen from its peak to a level which varies little with site class. Generally, these stands are fairly open and

have remnants of the old stand interspersed with younger ingrowth. There is a difference between yields from upland and lowland sites, however. Company data show that 158 m^3/ha (17.6 cords/acre) of spruce are being obtained from overmature lowland forest and only 98 m^3/ha (10.9 cords/acre) of spruce are being harvested in overmature upland forest. (In this instance, overmature stands are considered to be those that would be 140 or 150 years old under the F.R.I.) Thus, company and local OMNR foresters believed that it was important to separate stands into upland and lowland categories.

A second reason has to do with differences in the growth patterns followed by stands. F.R.I. site classes are assigned on the basis of stand height at age fifty. However, differences between sites sometimes cause the shapes of the growth curves to vary, with the result that some stands grow through one or even two site classes. Unfortunately, there are no data that indicate how widespread this phenomenon is; it is thought to be common and would be accentuated in older stands. As a result, the site class attributed to a mature or overmature stand may not reflect its entire growth curve.

Differences in wood storability between sites further reduce the reliability of the F.R.I system for predicting the behaviour of overmature stands. It is known that black spruce stands on the average upland site lose about 25-50% of their peak volume between ages 110 and 130, whereas this large volume drop occurs between the ages of 135 and 150 on the average lowland site. It has also been observed that the timber in stands on poorer sites generally stores longer than it does on better sites (OMNR, 1982; Smith, 1983). This effect tends to disrupt the F.R.I. site class assessments - overmature

class three sites, and to a lesser extent, overmature class two sites appear to belong to a higher site class. Evidence that this phenomenon is occurring can be seen in Table 2 which shows that only five per cent of the study unit area is site class three. This is remarkably low.

Table 2

Spruce Working Group Areas Shown by Site Class.

	Hectares	% of Productive Area
Site Class X	7,615	1
Site Class 1	402,755	56
Site Class 2	273,884	38
Site Class 3	38,376	5
Total	722,630	100

The final reason for distinguishing upland and lowland sites was that management prescriptions are largely determined by site type, not site class.

The upland/lowland classification has not solved every problem. It is open to question whether the percentage of softwood cover is an accurate basis for distinguishing uplands from lowlands. Secondly, since the site class grouping has been largely discarded, the regeneration program for a site must be based on one less piece of data. In fact, it was this very problem that led to site class being used to allocate the lowland stands into managed and unmanaged managed.

Data Preparation

The sample management area was last inventoried by the F.R.I. in 1972. Using company information, harvest cuts made after 1972 were mapped onto F.R.I. maps at a scale of 1:63,360 and subsequently transferred to 1:15,840 F.R.I. maps. The cutover areas were assumed to have been regenerated according to the management scenarios used in this study. Stand ages were increased by fourteen years to complete the update of the 1972 inventory.

The existing barren and scattered[1] stands were assumed to require thirty years to reach free-to-grow[2] and so were assigned an age of negative 16 years.

The forest was divided into five harvest regions. Each region is characterised by the age composition of the stands, which in turn is largely determined by the fire history. The lands in each region are not necessarily contiguous. The regional boundaries were drawn by referring to company fire records and by calculating the average stand age (weighted by area) in each township.

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[1] "Barren and Scattered" is defined in the F.R.I as productive forest land which, because of natural or artificial disturbance, contains only scattered trees (stocking below 0.25) or no trees at all, with either shrub cover or bare soil and no significant amount of regeneration. Treatment is required to restore such areas to productivity (OMNR, 1986).

[2] Free-to-grow stands are those that meet stocking, height, and/or height growth rate standards, as specified in the ground rules and are judged to be essentially free from competing vegetation (OMNR, 1986).

The harvest areas are described below, with the area of each in parentheses:

Region 1: Current harvest area. The calculated average stand age in 1986, less barren and scattered, was 123 years (33,581 ha).

Region 2: Area due to be harvested once Region 1 has been cut. Stand age is generally between 100 and 125, averaging 112 years. (81,938 ha).

Region 3: The 1895 burn area, as identified by company records. Roughly 50% of the burn is upland and 50 per cent is lowland. The expected stand age is 91 years, but the actual average is somewhat higher at 99 years. (133,838 ha).

Region 4: This region will be cut once Regions 2 and 3 are depleted. The average stand age is 99 years (95,319 ha).

Region 5: The 1923 burn area, according to company records. The actual average age is 82 years. (87,670 ha).

To simulate the progression of road building and harvesting activities, it was necessary to identify existing roads, priorities

for future road construction and the section of road that would give access to a stand. The present road network and roads proposed for construction up until 1995 were mapped. Large sections of the management unit will still be inaccessible in 1995, so the road network needed to fully access the working circle was approximated. It was judged that a combination of skidding and hauling on tertiary roads would bring wood from as far as 2.4 kilometers to the side of a primary or secondary road. This is in keeping with the density of the existing roads.

To model the road network, each existing and proposed road was assigned a number. Proposed roads were divided into kilometer-length intervals and the distance from each interval to an existing road was measured. Each newly constructed kilometer of road could be uniquely identified by its road and kilometer number. An existing road was designated by its road number and a distance number of zero. Next, each stand accessed by a particular road segment was tagged with the road number and distance. Stand harvesting drives road construction in the model. Hence, it was essential to ensure that each kilometer of proposed road accessed at least one stand.

It was also essential that each kilometer of new road be preceded by road kilometers that all had at least one stand with a harvest priority at least as high as the highest priority stand in the kilometer in question. The model would not work properly if a proposed road ended amid stands in a higher priority region (say Region 1) after passing through stands in a lower harvest region (say Region 2). The Region 1 stands at the end of the road could not be cut until Region 2 became eligible. To avoid this, the Region 1

stands were placed in Region 2 if their total area was less than approximately 250 hectares. Otherwise, at every kilometer length interval, small stands were classified as being in Region 1 in order to drive road construction. Currently accessible stands can be cut whenever the region that they fall into becomes eligible for harvest.

The yield tables used in this study were made using a combination of Smith's volume tables (Smith, 1983), company permanent yield plot data and harvest records, and local knowledge. They are presented in Table 3 and shown in graphical form in Figures 1A and 1B. Yield tables were formulated for different levels of management on the

Table 3

Gross Merchantable Volumes Of Softwood Component By Stand Type (m^3 Per ha)

Age	Unmanaged Upland	Mixed Wood Upland	Spruce Upland	Unmanaged Lowland	Managed Lowland	Jack Pine
10	0.0	0.0	5.4	0.0	1.8	0.0
20	0.0	0.0	11.6	11.6	14.3	8.1
30	0.0	7.2	39.4	26.0	33.1	24.2
40	2.7	18.8	65.4	41.2	55.5	44.8
50	10.7	37.6	101.2	60.0	82.4	67.2
60	25.1	58.2	143.3	82.4	112.0	94.9
70	44.8	85.1	200.6	107.5	146.0	128.1
80	68.1	121.8	261.5	136.1	186.3	169.3
90	99.4	170.2	296.5	172.0	223.0	217.6
100	122.7	203.3	311.7	196.1	261.5	245.4
110	137.0	219.4	309.9	209.6	284.8	256.2
120	143.3	222.1	292.9	217.6	297.4	255.3
130	138.8	213.2	255.3	222.1	300.9	235.6
140	120.9	179.1	190.8	218.5	288.4	154.9
150	96.7	113.7	120.9	172.0	215.0	92.3
160	67.2	77.0	77.0	116.4	128.1	72.7
170	56.4	56.4	56.4	100.3	103.9	55.5
180	53.7	53.7	53.7	89.6	89.6	53.7
190	53.7	53.7	53.7	89.6	89.6	53.7

Figure 1A. Yield Curves Upland Sites

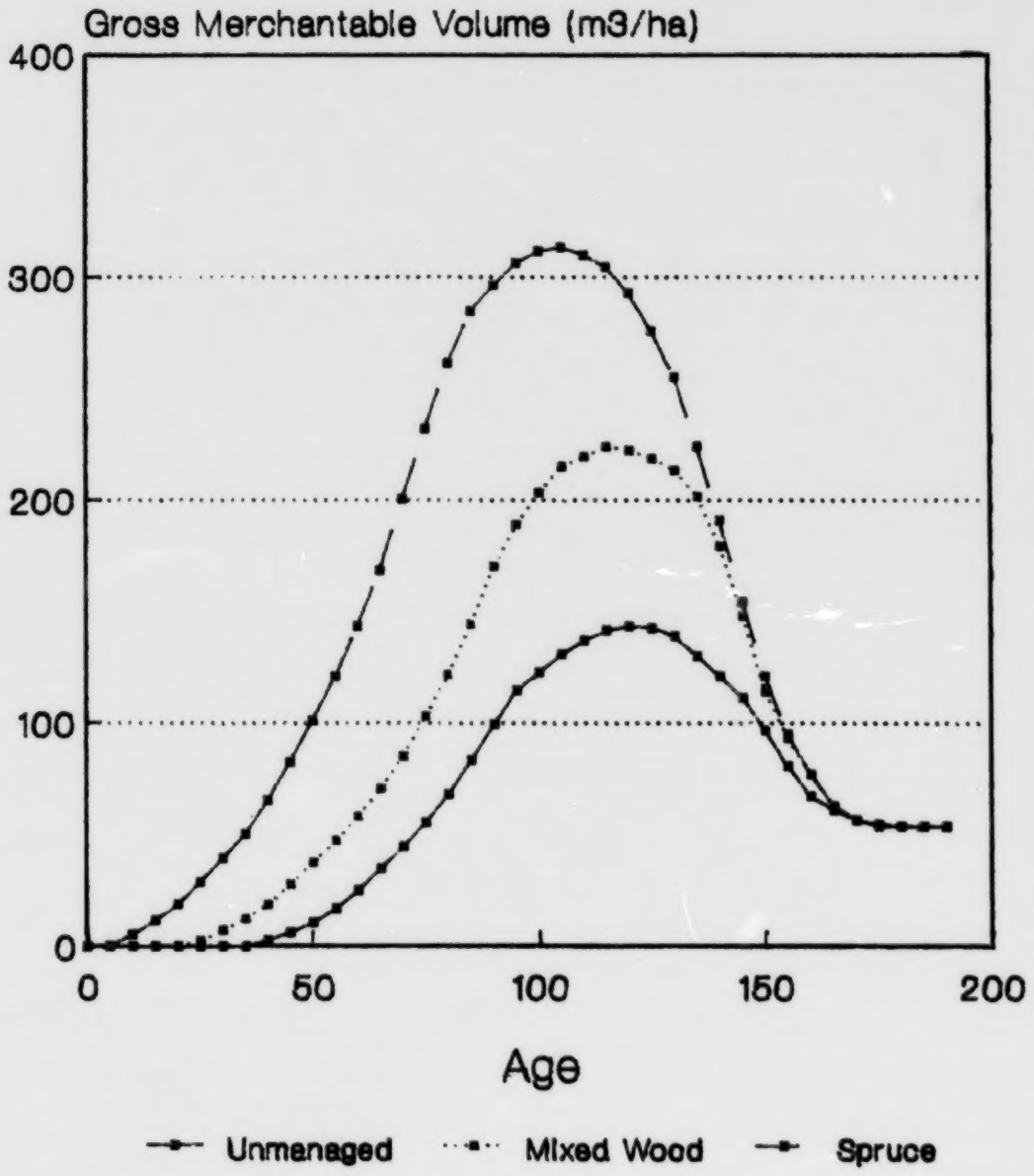
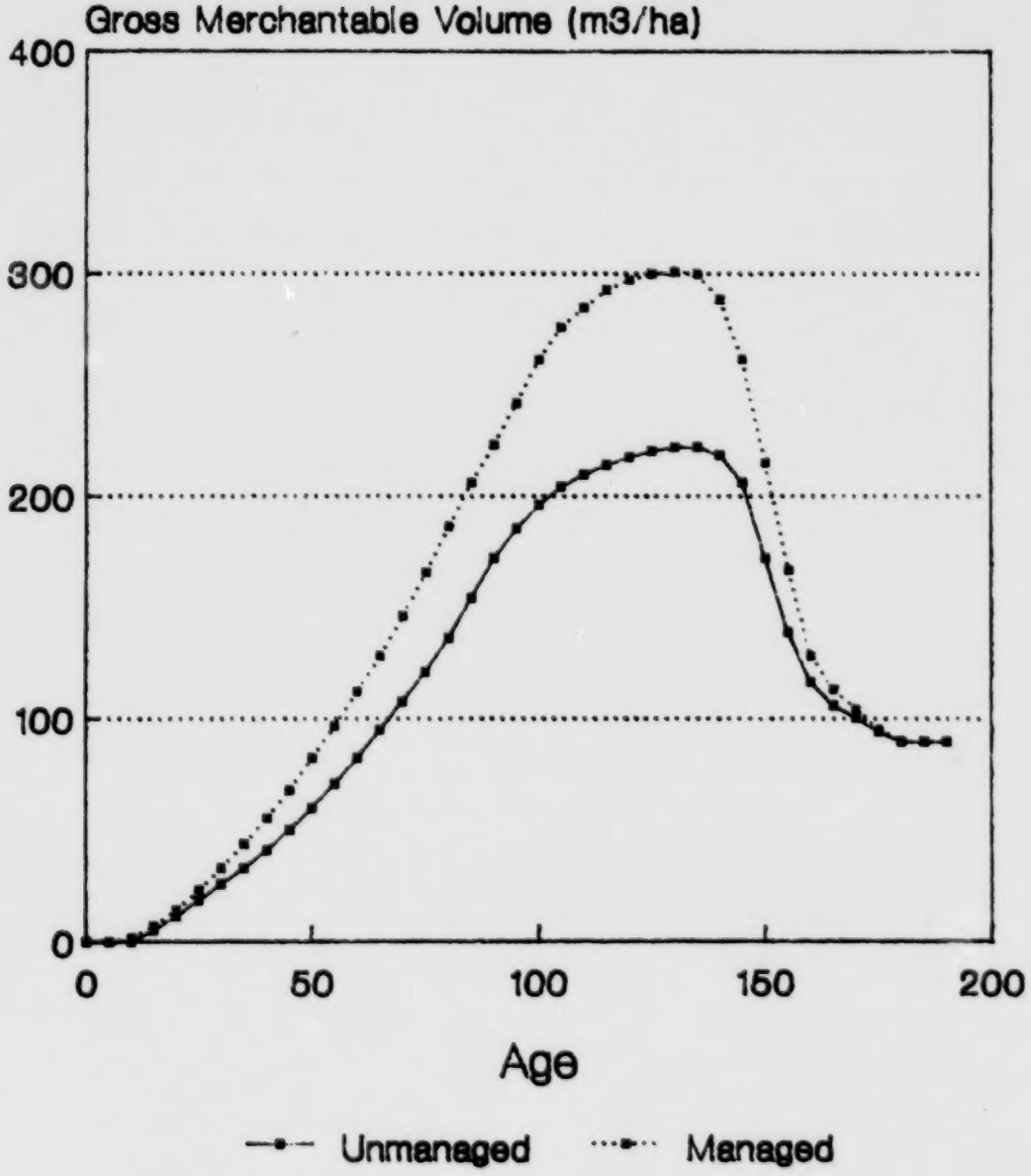


Figure 1B. Yield Curves Lowland Sites



two main site types. They reflect the typical pattern of yield increase. A mature, rotation-aged stand adds volume (per unit area) at a slow and diminishing rate. During this period, a stand may suffer a small, temporary reduction in volume (OMNR, 1982). As it becomes overnature, the stand's volume begins to fall gradually at first and then dramatically. In this phase of rapid stand break-up, as much as 50% of the peak volume may be lost within ten to fifteen years. Thereafter, openings in the broken up stand are filled by young trees. During this period of time, stand volume stays fairly constant at a low level, until the growth of the next stand begins to dominate the site. Subject to variation, this pattern occurs in most stands (see Plonski, 1960; Smith, 1983).

Since all pre-1972 stands are assumed to be unmanaged, this begs the question of whether the unmanaged upland yield table accurately reflects the reputedly high yields on the 1895 burn. It seems that it does, based on average yields. Company data show that lowland sites presently yield 172 m^3/ha (19.3 cords/acre) of spruce and uplands yield 99 m^3/ha (11.1 cords/acre) on the 1895 burn. These company data correspond closely to the yields used here.

The proposed silvicultural treatment programs and rotation lengths on each site and management class are summarized in Table 4. They are derived from the treatments currently employed under the ground rules of the company's FMA. The costs are the amounts paid by the Ministry to the company for doing the silvicultural work, and are part of the Ground Rules.

The series of treatments on managed lowland was selected by drawing upon company and Ministry experience and the Ground Rules used during the previous five-year period. Half of such sites require site

Table 4

Summary of Silvicultural Treatments, Related Costs and Rotations

(Probability of Treatment Below Cost; Costs in $/ha)

Site Type	Site Prep. Year	Site Prep. Cost	Planting Year	Planting Cost	Tending 1 Year	Tending 1 Cost	Tending 2 Year	Tending 2 Cost	Free-to-Grow Year	Rotation Year	Equivalent Annuity
Unmanaged Upland	N/A		N/A		N/A		N/A		11	86	42.70
Mixed Wood Upland	0	123.98 (1.0)	1	249.83 (1.0)	4	36.10 (1.0)	7	36.10 (0.4)	11	86	60.55
Spruce Upland	0	287.40 (1.0)	1	499.65 (1.0)	4	36.10 (1.0)	7	36.10 (0.4)	11	86	119.40
Unmanaged Lowland	N/A		N/A		5	36.10 (1.0)	9	36.10 (1.0)	19	121	36.52
Managed Lowland	0	310.56 (1.0)	1	226.63 (0.75)	5	36.10 (1.0)	9	36.10 (0.1)	13	91	81.06
Jack Pine Upland	0	287.40 (1.0)	1	420.58 (1.0)	4	36.10 (1.0)	9	36.10 (0.1)	8	86	76.90

preparation so the expected site preparation cost per hectare of managed lowland is 50% of the full rate, or $155.28/ha. The planting cost on this site type reflects the diversity of treatments that comprise the treatments category HAR01, which is a combination of lowland treatments. Forty per cent of the site prepared area (20% of the managed lowland area) is assumed to be planted at the rate of 2,500 bare root stock per hectare, 50% of the untreated area (25% of total area) is seeded and the remaining 55% of the total area is left to natural regeneration. These estimates are based on current practice. As experience is gained, the company hopes to lower the percentage of area that is planted or seeded from 45% to 30%.

Table 4 also shows the equivalent annuities generated under each management program, calculated on the basis of a 3% real annual discount rate.

Originally, a rotation age of 120 years was used for all lowlands, which made the managed lowland less profitable than the unmanaged lowland. This would discourage investment. The rotation age was based on the growth rate of natural stands, which for some 20 to 30 years grow slowly beneath the alder and willow that often regenerates after harvest. When the spruce emerges from the alder and willow canopy, it grows rapidly. Tending should remove much of this delay and therefore a 90 to 100 year rotation would be appropriate for regenerated stands. The rotation should be further shortened if advance growth is left healthy after logging. A further benefit from retaining advance growth is the preservation of the moss layer and some shade, which together provide ideal moisture conditions for young spruce. Site preparation upsets this balance and time is required to redress it.

From this evidence, it is not unreasonable to think of rotations being as low as 75 years on managed lowlands. A more conservative value, 90 years, was finally selected.

The opportunity cost is the financial gain (or loss) that is incurred by not doing something, which in this case is cutting the stand now and investing the return. Hence, the opportunity cost is the difference between the value added obtainable by cutting the stand now and the discounted worth of the value added that would be obtained if the stand were cut in one year's time. The opportunity cost equals: (1) the change in stand value due to volume growth or loss in the coming year, discounted one year; minus (2) the interest forgone on the value of timber because it was left on the stump; and minus (3) the cost associated with delaying future rotations by one year. A real interest rate of 3% per annum was used to discount future returns and was assumed to be the rate at which present investments would gain value.

Table 5 shows the opportunity costs for each management type at five-year intervals, calculated on the basis of the yields and silvicultural programs summarized in Tables 3 and 4.

Look under the "Unmanaged Upland" column. The opportunity cost is not the same at all ages - it may be positive or negative. A positive opportunity cost signifies that the value gained by letting the stand grow for one year outweighs the indirect costs of doing so. On this site type, the graph of opportunity costs over time has an S-shape, increasing to a positive peak at sixty years, and falling to a low at 150 years before rising to an equilibrium level (-$364.90) at 180 years. When opportunity cost is compared with volume and volume growth

Table 5

Opportunity Cost By Forest Type ($ per ha)

Age	Unmanaged Upland	Mixed Wood Upland	Spruce Upland	Unmanaged Lowland	Managed Lowland	Jack Pine
10	-42.70	-60.55	-119.40	177.48	178.48	67.10
20	-42.70	-60.55	-119.40	179.88	180.78	160.50
30	-42.70	-60.55	-119.40	93.48	94.38	171.90
40	85.10	67.25	8.40	74.28	75.18	84.30
50	143.10	125.25	66.40	33.48	34.38	21.90
60	200.70	182.85	124.00	-28.92	-28.02	-2.30
70	118.50	100.17	41.80	-143.52	-142.62	-57.50
80	158.70	140.85	82.00	-137.12	-136.22	17.30
90	-29.10	-46.95	-105.80	-530.52	-529.62	-702.50
100	-456.90	-474.75	-533.60	-891.12	-890.22	-1263.30
110	-684.70	-702.55	-761.40	-1114.12	-113.22	-1578.10
120	-938.50	-956.35	-1015.20	-1234.12	-1233.22	-1716.70
130	-1233.50	-1251.35	-1310.20	-1369.12	-1368.22	-2564.50
140	-1162.10	-1178.95	-1238.80	-1849.52	-1848.62	-2546.30
150	-1266.90	-1284.75	-1343.60	-2394.52	-2393.62	-1346.70
160	-695.90	-713.75	-772.60	-1164.92	-1164.02	-667.10
170	-453.10	-470.95	-529.80	-888.32	-887.42	-481.90
180	-364.90	-382.75	-441.60	-574.12	-573.22	-399.10
190	-364.90	-382.75	-441.60	-574.12	-573.22	-399.10

behaviour (see Table 3), the behaviour of the opportunity cost curve can be explained. High growth rates and relatively low volumes give rise to positive opportunity costs. As stand volume increases and its growth rate falls, the opportunity costs fall and become negative. The greatest (negative) opportunity costs arise when the stand has a high volume and a high rate of volume decline. At 180 years, the opportunity cost value stabilizes because there is no net volume growth. However, this is a rejuvenation period when the remnants of the old stand are replaced by ingrowth. By the end of this period, the original stand character has disappeared. Among the various stand types, lowland stands have higher maximum volumes than upland stands. For this reason, they also have higher opportunity costs at each stage of development.

The Harvest Policy Scenarios

The harvest scenarios have several common features. These are outlined below, followed by a description of each individual scenario. In all cases, the current forest is treated as a single working group under one management regime. The rotation age of the spruce working group, 110 years, was selected as the unit rotation age and the age of free-to-grow was set at 18 years, equal to the age of free-to-grow on the poor lowland sites. Stands below a certain age, designated the "age of maturity", will not be cut under any circumstances. This was set at 80 years. This age was selected because it was assumed that unmanaged stands younger than 80 years are not mature enough to be cut under any of the policy alternatives envisaged here.

The MAD was determined by an area allotment procedure simpler than that used in the FMA regulations. The base consists of two parts: virgin forest older than free-to-grow and post-1972 cutovers that have entered free-to-grow. The contribution of the first part to the MAD equals the virgin forest area older than free-to-grow divided by the number of years between the ages of free-to-grow and rotation, 92 years in this case. Post-1972 cutovers were assigned to one of six management regimes and the area older than free-to-grow was again divided by the number of years between the appropriate free-to-grow and rotation age. This was the second part of the MAD.

A non-accelerated allotment procedure was adopted because this is in keeping with Ministry practice - FMA holders declare what percentage of of the MAD they intend to harvest and declare the remainder as surplus.

All scenarios run on a year-by-year basis. That is, every year the model tests to see whether it is necessary to build more roads and every year the company harvests the MAD. In any year, roads are extended if the currently accessible stands do not allow the MAD to meet the minimum requirements set out under each scenario. Road construction may be unnecessary in some years.

The preferred sites and opportunity cost scenarios have economic selection criteria: the value of future stands on the site and the direct and indirect costs of keeping the current stand, respectively. The operation of these scenarios depends on the value assigned to a cubic metre of timber. The appropriate value is the value that the processing and sale of that cubic metre of wood adds to the provincial economy. The economic term for this is "total value

added". It includes the value added to the wood as its physical form is modified, the value of the wages of the labour employed to manufacture and sell the finished product and the value of the equipment and machinery needed for these purposes. In this case, most of the harvested timber is pulped and so the value added was estimated to be $\$200/m^3$. This figure, based on January 1985 newsprint prices ($650 Cdn/tonne) and the company's pulping efficiency, was used in all simulations.

1) Oldest First: This is the current rule. However, it is not practised in the literal sense. Instead, the manager allocates much of the cut to stands older than some age which the manager feels will satisfy the rule. This description is very general because forests are managed on a unit-specific basis. However, the manager will not often pass by stands approaching overmaturity but younger than this benchmark age. The higher the minimum age of "oldest" stands, the more closely the model simulates an oldest first policy.

   To simulate this scenario, the user selects an age at which stands become "oldest". Stands of this age or older are the target stands. This age was always chosen above the rotation age. Then roads are built until stands which can provide at least a pre-selected percentage of the MAD (always 70% here) are accessible. Hence road building is driven by the accessibility of "oldest" stands. As much of the MAD as possible is taken from accessible "oldest" stands. If there are too few target stands to

make up the full MAD, then the remaining accessible stands which are above the age of maturity are listed in order of decreasing age class. From the top of the list downwards, stands are allocated for harvest until the full MAD is assigned. The MAD remains unfilled if there are insufficient accessible non-target stands.

2) **Minimum Sufficient Road Extension:** In this scenario, the entire MAD is taken from stands at least as old as the age of maturity. The cutting schedule does not depend on any other criterion. This scenario was thought to approximate how a company would harvest in the absence of the oldest first orientation.

3) **Preferred Sites:** This scenario might be followed if the forest management goal was to return valuable but over-mature sites to active production. When accomplished, a smaller production forest than currently exists would be able to supply the present harvest volume. This scenario is the only one considered here in which enhancing future yields is the paramount objective. Present harvests are not at issue here, because preferred sites may not be valuable in the absence of appropriate management.

In the absence of an inventory of forest land based on soil productivity, the company forest stand delineation system (e.g., upland, lowland) was used in combination with the F.R.I. site classes to approximate the designation of "prime sites". The Ministry defines a prime site as a forest site on which timber

grown under a management program for a series of rotations yields a capitalized net value per hectare exceeding some pre-selected benchmark figure. Whether a particular site is prime depends not only on the yield of timber, but the speed at which it is produced, its species composition, and the costs of the silvicultural activities needed to produce it. Because this study only approximates the selection of prime sites, the term "preferred site" will be used in its stead. For the purpose of this study, a preferred site is defined on the basis of the annualized discounted total value added it can be expected to yield.

To simulate this scenario, the user must identify the preferred sites. Biological productivity was given by the yield tables shown in Table 3. The cost of silviculture and the rotation length are the non-biological factors which affect a site's value yield. These are shown in Table 4. From this information, equivalent total value added annuities from each stand management program are calculated and displayed on the computer terminal. These values are used to select the preferred sites. The user submits an annuity value which stands as the minimum permissible annuity yielded by a preferred site.

In this scenario, an exact percentage of the MAD is taken from preferred site stands. The remainder comes from non-preferred stands. As in the oldest first (scenario 1), non-target stands are ordered by decreasing age and the remaining portion of the MAD allocated on the basis of oldest first. Unlike scenario 1, when

the non-target portion of the MAD cannot be obtained up from currently accessible stands, roads are extended until this becomes possible. Thus, road construction may be forced by either the preferred site or non-preferred site quota.

4) **Opportunity Cost:** The aim of this scenario is to stem the loss of value in the forest estate by cutting stands just before or during breakup. This is done by allocating the cut according to the opportunity cost of leaving stands unharvested for one year.

In this scenario, the target stands are those with at least a minimum opportunity cost per hectare. The user sets this value. Non-target stands are young stands and overmature stands which have already suffered a large decline in merchantable volume. The user also submits a percentage of the MAD to be filled by target stands; the program does this exactly. The remainder of the MAD comes from non-target stands selected on an oldest first basis. In this scenario, as in the preferred sites scenario, road building is driven by the search for either target or non-target stands.

Simulation Results

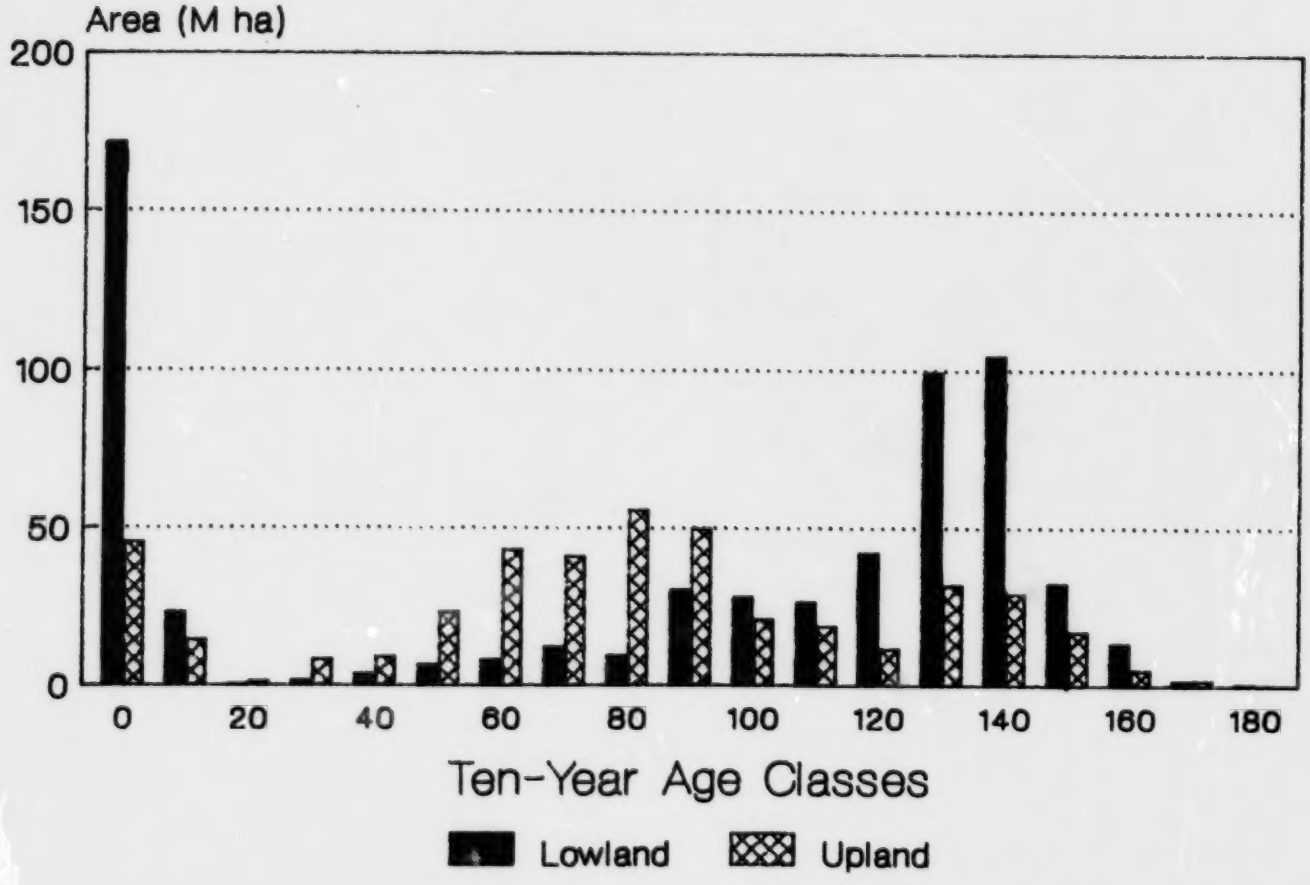
Before comparing the results under the different scenarios, it is worth investigating how each scenario behaves when some of the main parameters are adjusted. This will illuminate the effects of the age and site type distributions on allocation results under each rule.

The four scenarios are examined separately in the next four sections. Each section begins with tables summarizing the characteristics of each run and the main results. The behaviour of each allocation rule is described in some detail and the annual timber flows from two or three runs are shown.

The current forest is the foundation upon which forest management prescriptions must rest and the discussions of the four scenarios reflect this. In this study unit, the characteristics of the allocations are heavily influenced by the age-class structure of the upland and lowland sites in the current forest. Figure 2 is a histogram of the area under each age-class separated into lowland and upland types. Most of the over-mature stands are on lowland sites, which prompts the question: "Why do the two site types have such different age-class structures?" The different biological growth pattern and perhaps a lower incidence of fire on lowland sites are the most likely reasons. However, our information is incomplete because a documented description of both collapsed upland and lowland stands is not available.

The annual timber flows are quite volatile. In particular, there is often a sharp change at each ten year interval, and sometimes at the mid-point of that decade. The reason is that stand ages cannot be estimated more accurately than to the nearest five or ten years. In the F.R.I., they are frequently divisible by ten and most other ages end with the digit '5' (e.g. 75,85,95). Thus, the group of stands in the target range tends to change dramatically every ten years, with a smaller change at the five-year mid-point.

Figure 2
Structure of Sample Forest



Discounted road costs are shown in the summary tables. Discounted cost, rather than total mileage cost or total mileage, is the more important statistic and also proved to be the most revealing. This is because the timing of road construction is so important. In the more restricted cutting scenarios there was a good deal of mileage built within the early years. Besides increasing the present value of the expenditure, this added to the length of time that maintenance costs must be paid.

Scenario 1: Oldest First

Five runs will be compared. The specifications used in each one are listed below in Table 6. Table 7 summarizes the important total cut and road construction statistics.

Table 6

Descriptions Of Five Oldest-First Runs

Run No.	Minimum Age Of Old Stands	Minimum % Of MAD From Old Stands	Year When 1895 Burn Stands Become Eligible	Length Of Run (Years)
1	120	70	0	60
2	140	70	0	60
3	150	70	0	48
4	140	70	25	60
5	150	70	25	48

Table 7

Summary Statistics Of Five Oldest First Runs

Run No.	Total Vol. Cut (10^6 m^3)	Vol. Left In Old Forest (10^6 m^3)	Discounted Road Cost Per m^3	Total Discounted Road Costs	Harvest Volume Per ha	Pct. Lowland Area Cut
1	80.6	11.7	$ 1.15	$ 92.8 X 10^6	142.87	53
2	77.0	22.5	1.45	111.3 X 10^6	136.82	61
3	55.6	40.2	2.57	140.2 X 10^6	124.39	72
4	76.3	22.4	1.49	113.6 X 10^6	135.52	61
5	54.3	40.3	2.52	136.7 X 10^6	123.60	72

The results show the importance of carefully selecting the "oldest" age limit. A higher limit reduces the volume obtained and increases road costs significantly. This is easily understandable. A higher age limit means that fewer stands are eligible for harvest and more access must be quickly provided to satisfy the harvest restriction. The volume decreases because older stands supply the bulk of the harvest. Only a small reduction in harvest volume occurs when the limit is raised from 120 to 140 years. This is due to two factors. Firstly, so much of the cut in the initial decades is composed of stands older than 140 years that tightening the restriction has little effect. The second contributing factor is that as the restriction is tightened, a higher proportion of lowland is cut. Because lowland stands still gain volume after 120 years, there is actually a volume gain for harvesting at 140 years rather than 120 years. This effect is especially prominent in the first twenty years of the simulation when approximately 80% of the cut is from lowlands.

It is not surprising that delaying the harvest of stands resulting from the 1895 burn has so little effect. These stands twenty years younger than the 120-year limit and will not be cut extensively until they reach that age. At this time, the 25-year delay period will have almost elapsed. Also there will actually be a volume increase in these stands if one waits 25 years to cut them (see Table 3).

Figures 3 and 4 show the yearly harvest volumes in runs #1 and #2 respectively. In both cases, the harvest declines during the first twenty-five years and remains low for the subsequent ten years. Concentrating the cut on the oldest stands removes the more storable lowland stands first. These begin to collapse at age 140. By the time the bulk of the lowland forest has collapsed or been cut, the eligible upland stands have lost much of their volume. The oldest first scenario does not cut the old lowlands fast enough to get to the upland stands while they are still merchantable. The movement of more old upland into the target age range exacerbates the volume drop in the harvests because the oldest first rule does not discriminate between upland and lowland sites. At this stage, the upland has lost much of its volume. Lowering the age limit from 140 to 120 allows some earlier cutting on the upland sites, increasing the harvest volumes in most of the first thirty-five years.

More detailed analysis reveals that the area of lowland forest older than the minimum age falls by 40% between years 40 and

Figure 3. Annual Harvest Volumes Oldest First, 70% cut 120 and older

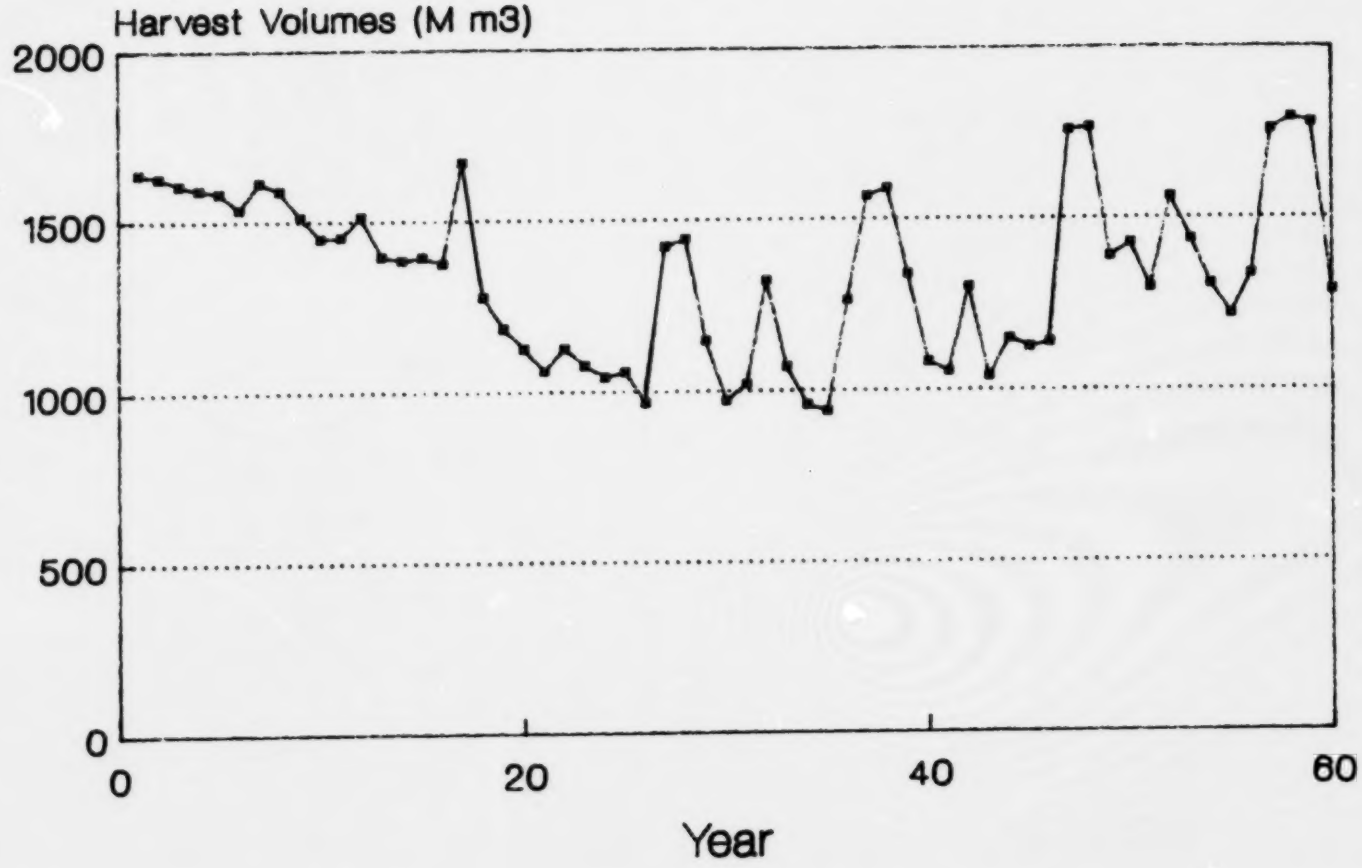
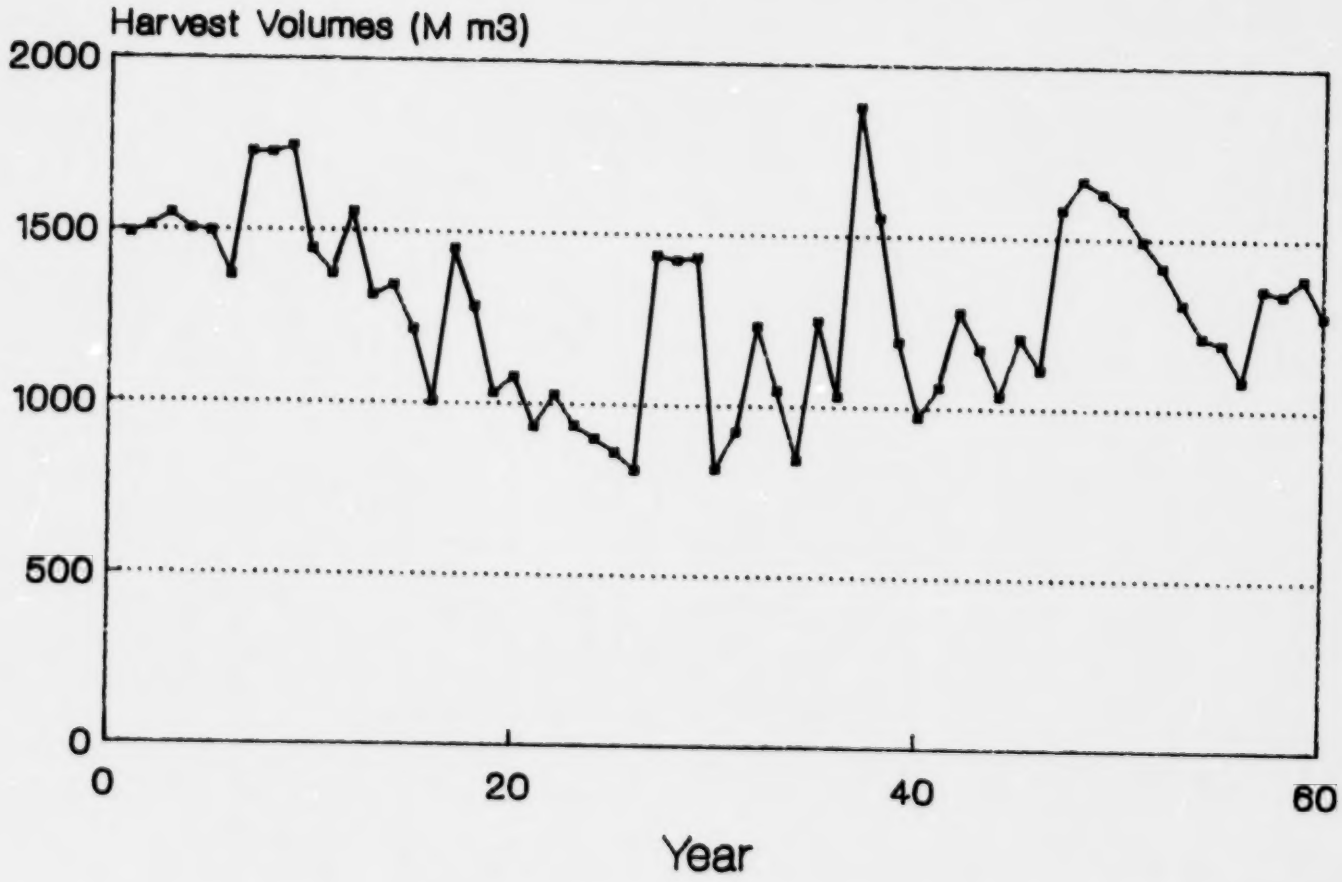


Figure 4. Annual Harvest Volumes Oldest First, 70% cut 140 and older



60. This may indicate that a substantial area of lowland reaches the age at which it becomes classed as new forest.

Scenario 2: Minimum Sufficient Road Extension

This scenario can be viewed as being a member of the family of oldest first scenarios, but with a low minimum age. The harvest totals is shown below in Table 8. In run #6 the 1895 burn is immediately accessible, whereas it is only accessible after 25 years in run #7.

TABLE 8

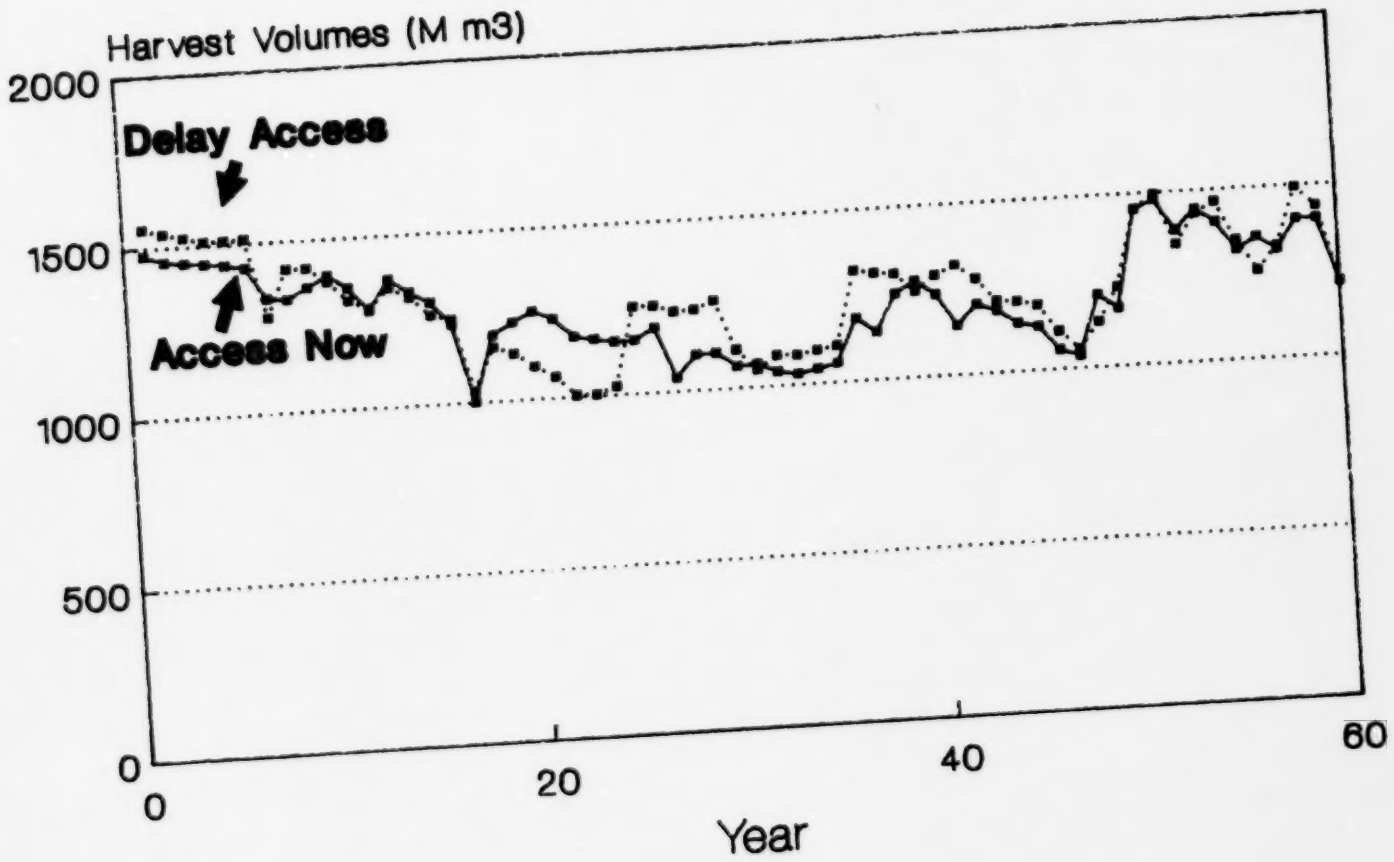
Summary Statistics Of Two Minimum Road Extension Runs

Run No.	Total Vol. Cut (10^6 m^3)	Vol. Left In Old Forest (10^3 m^3)	Discounted Road Costs Per m^3	Total Discounted Road Costs	Harvest Volume Per ha	Pct Lowland Area Cut
6	74.8	11.2	1.02	76.1 X 10^6	131.44	52
7	76.2	11.4	1.12	85.6 X 10^6	134.04	52

Here, one would expect to see the date of eligibility of these stands have a greater impact than it did in scenario 1. This is indeed the case: delaying their eligibility substantially increases the road costs because the road network must be expanded more rapidly. Despite the increased maintenance charges that result, immediate access lowers road costs by over $9 million discounted.

Perhaps the most unexpected effect of delaying the date when these stands are eligible is that the total harvest volume rises. Figure 5 shows the timber volumes cut in runs #6 and #7.

Figure 5. Annual Harvest Volumes Minimum Roads Extension



When stands from the 1895 burn are immediately eligible, the volumes cut in most of the first forty-five years are lower than when entry is delayed. In fact, only between years 18 to 24 is the annual volume cut higher if these stands are immediately harvestable.

During the first twelve years, more of the cut comes from lowland stands with higher volumes per hectare when access to the burn is delayed. The stands in the 1895 burn are still growing rather rapidly as the simulation begins. By year 18, higher volumes in the stands resulting from the burn and declining volumes in the over-mature stands mean lower harvest volumes are obtained by delaying access to the burn. This situation reverses at year twenty-five, when these stands becomes available. Waiting twenty-five years makes these stands accessible when their volumes are peaking, resulting in the long period of higher harvest volumes.

However, the road cost per cubic metre is lower if immediate access is permitted because the savings in road costs are proportionally greater than the decrease in volume that accompanies this option.

Scenario 3: Preferred Sites

The behaviour of this scenario depends on which stand types are selected as preferred sites. Spruce upland and managed lowland were chosen as preferred sites in these simulations.

These two site types comprise 51.6% of the unit's area, a percentage which indicates that rather loose standards were used to identify preferred sites. Fifty-nine percent of the total unit area,

and 56% of the total preferred site area is lowland. Hence, 62% of the non-preferred area is lowland.

In the six sample runs, the percentage of the MAD furnished by preferred sites varies from 50% to 80%. (See Table 9.) In all cases, the 1895 burn was available from the start and the minimum harvest age was eighty years. Since more than half of the unit is cut during the simulation, one might expect the percentage of each site type in the cut to correspond closely to the unit-wide percentage occurrence of that site type. If 50% of the cut was allocated to preferred sites, then 59% of the cutover would be lowland. Increasing the preferred site content of the MAD should lower the incidence of lowland in the cutover. This does not happen. Instead, more lowland is cut as preferred sites are emphasized.

Table 9

Summary Statistics from Six Preferred Sites Runs

Run No.	% MAD From Pref. Sites	Total Vol. Cut (10^6 m^3)	Vol. Left In Old Forest (10^6 m^3)	Discounted Roads Cost Per m^3	Total Discounted Road Costs	Harvest Volume Per ha.	Pct Lowland Area Cut
8	50	75.7	11.2	1.05	79.7 X 10^6	138.02	53
9	60	75.9	14.2	1.10	83.3 X 10^6	133.72	54
10	65	74.4	17.9	1.19	88.8 X 10^6	131.46	58
11	70	71.6	21.6	1.30	93.1 X 10^6	128.86	62
12	75	65.3	25.9	1.49	97.2 X 10^6	126.59	63
13	80	62.6	29.3	1.62	101.2 X 10^6	126.01	61

As the percentage of preferred sites in the allocation is increased, total discounted road expenditures and road costs per cubic metre rise. Total volume cut falls only slightly as preferred sites supply more of the MAD, however, the decline is exaggerated in Table 9 because runs #11, #12 and #13 terminated early (at 59, 55 and 52 years, respectively). Early termination of the run could have been expected for preferred sites obviously can't produce much more than 51.6% of the MAD in perpetuity when the MAD is defined in area terms. The average annual harvest volumes (1.26, 1.27, 1.24, 1.21, 1.19, and 1.20 x 10^6 m^3 for runs #8-13 respectively) show only a gradual decline.

It is easy to explain the increase in road costs brought about by greater reliance on preferred sites: roads have to be built more rapidly and maintained for longer when two specific site types are increasingly depended upon for the harvest. It is surprising that more volume is cut as preferred sites are discriminated against. The annual timber flows from runs #8, #9 and #11 are shown as Figures 6, 7, and 8. Comparing them, the reader will notice that the annual volume cuts are generally higher when the percentage of the MAD from preferred sites falls.

To understand this, both the preferred and non-preferred parts of the cut must be considered. A look at Figure 2 will show how the types of stands cut change as the simulation proceeds. The non-preferred portion is taken on the basis of oldest first. Throughout the simulation, oldest first cutting will be concentrated in the stands which are currently 120 years and older. Most of these stands are lowland. If more non-preferred area is cut each year, younger stands will be allocated in the non-preferred MAD portion. The preferred site portion of the MAD consists of accessible

Figure 6. Annual Harvest Volumes Preferred Sites, 50% Cut

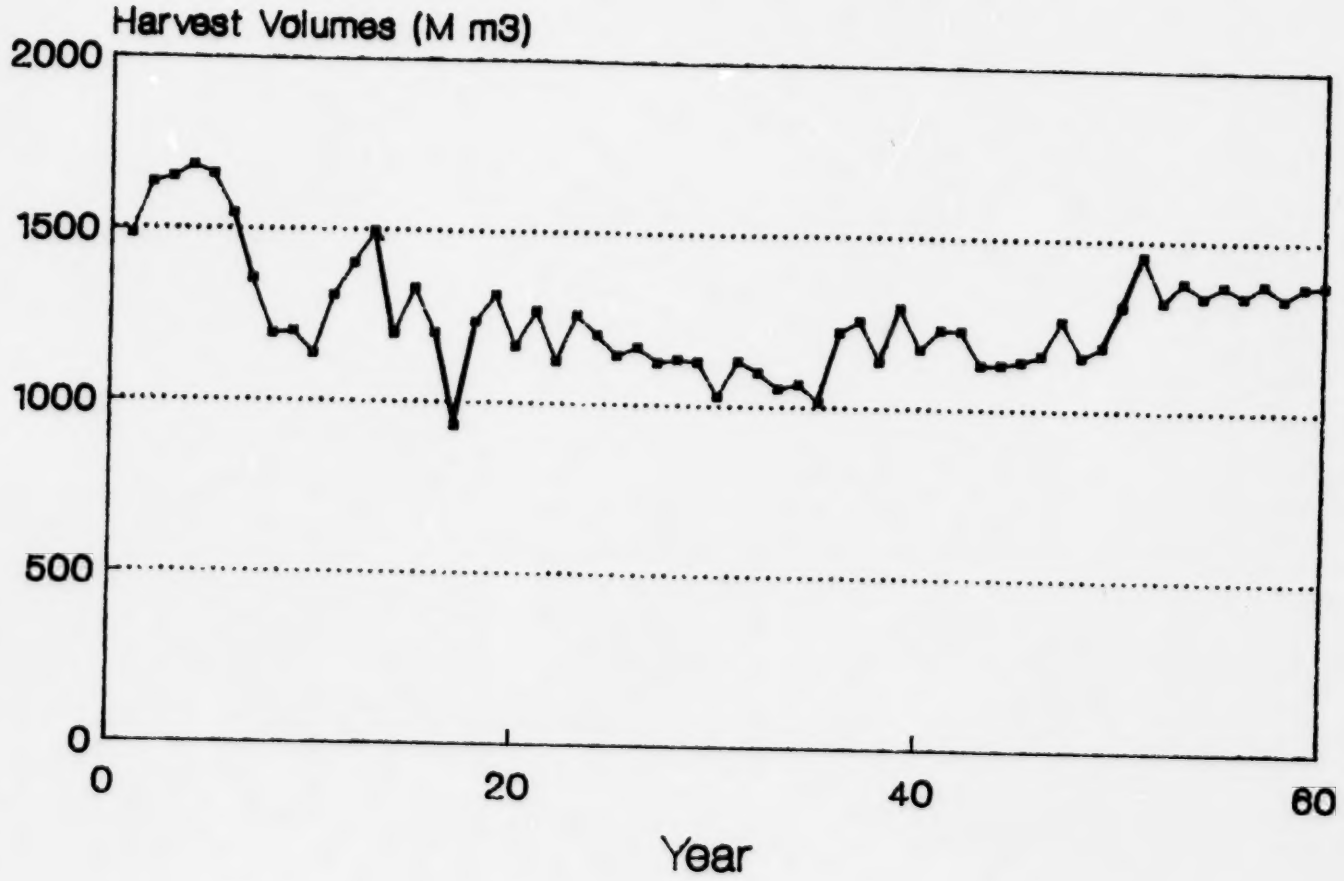


Figure 7. Annual Harvest Volumes Preferred Sites, 60% Cut

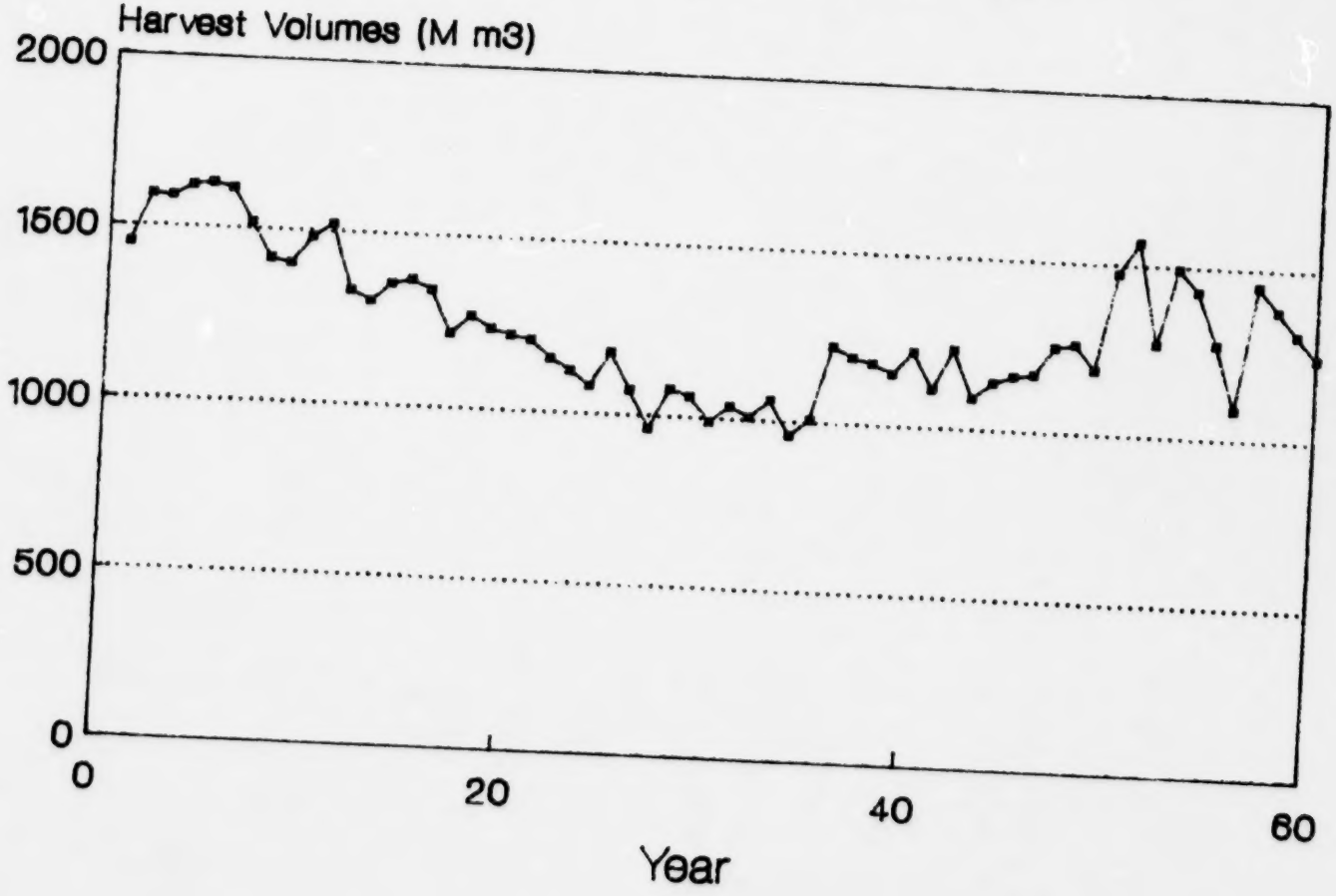
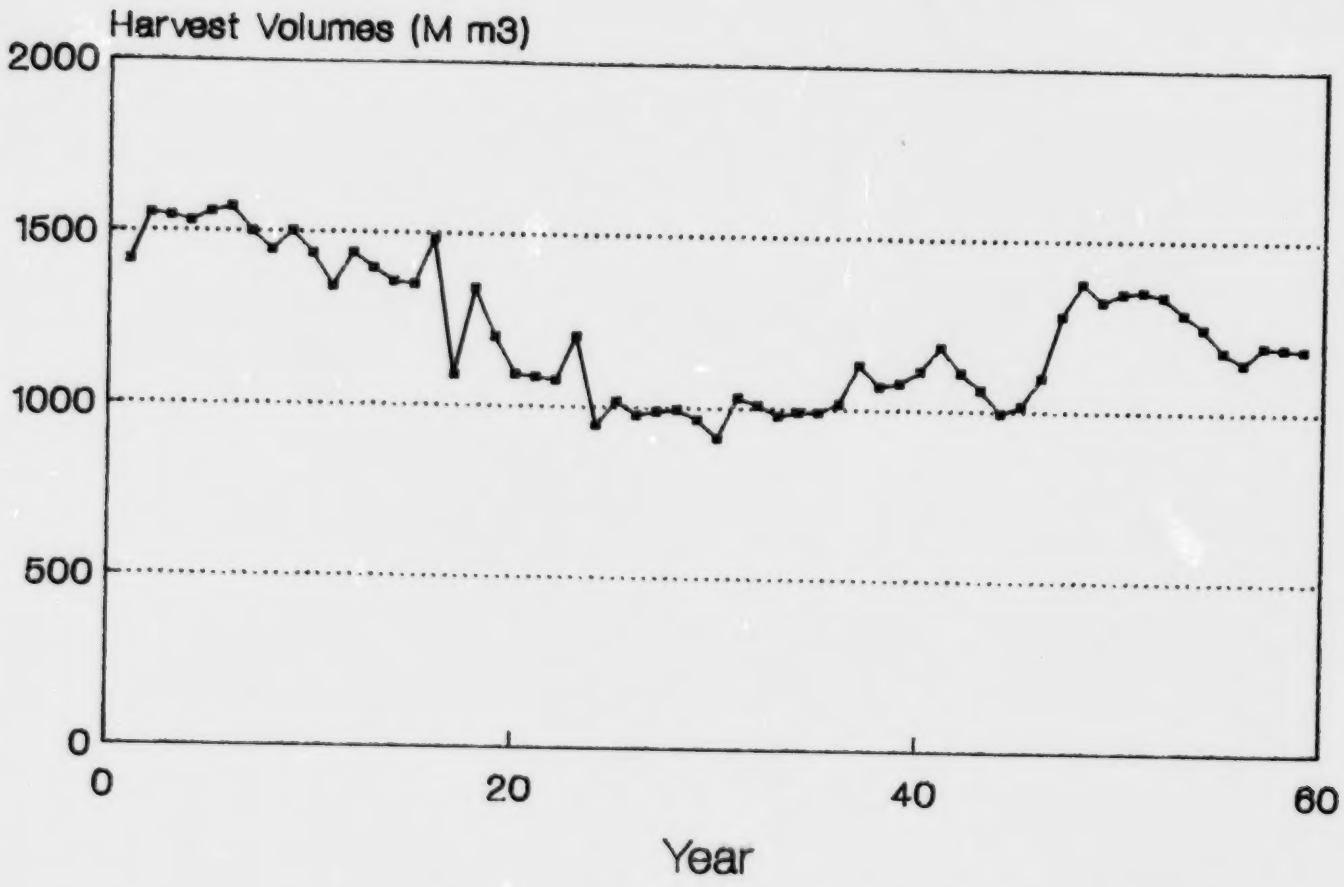


Figure 8. Annual Harvest Volumes Preferred Sites, 70% Cut



stands older than 80 years. The preferred stands in the 1895 burn will be allocated early in the simulation. They will be cut more heavily (and sooner) when the proportion of preferred sites in the MAD increases. However, preferred stands are cut as they are encountered. Therefore, once the 1895 burn is cut, the type of stand harvested will depend on what is encountered and for lack of more detailed information, one may assume that the percentage of stand types cut stays relatively constant. Therefore, the average age of stands in the preferred portion of the cut will rise throughout the remainder of the simulation, due to the dearth of stands presently younger than 60 years old (and older than 10 years).

Translating these effects into volume effects demonstrates that increasing the harvest intensity on preferred sites has short-term drawbacks. As the preferred portion of the cut increases, both the preferred and non-preferred portions yield lower volumes - the preferred portion because the 1895 burn and the currently 60 to 100-year old upland stands are cut relatively quickly and the non-preferred portion because only the oldest, lowest volume stands are cut. In contrast, splitting the allocation 50:50 between preferred and non-preferred sites slows cutting in the young upland and burn stands, allowing more of them to be cut at higher volumes per hectare, and at the same time more non-preferred stands are cut before they collapse.

This behavior is also evident in the harvest volumes per hectare (see Tables 9 and 10). Table 10 shows some selected statistics for years 20-39 of the simulation. The first three data columns show that in the 50% and 60% cuts, the non-preferred sites

have a significantly greater volume per hectare than the preferred sites. This is not always true for the 75% cut. The middle three columns of Table 10 show a marked increase in the percent volume cut from lowland as the percent preferred sites rises in the MAD. It is probable that reducing the prominence of the non-preferred stands raises that portion's percentage contribution to the lowland cut, simply because it is allocated by oldest first and the bulk of the oldest stands are lowland.

Table 10

Percentage Volume From Preferred Sites And From Lowlands And Volume Cut Per Hectare Between Years 20-39

% MAD From Pref. Sites	% Volume Cut From Pref. Sites			% Volume Cut From Lowland			Volume Cut Per Hectare (m^3)		
	50	60	75	50	60	75	50	60	75
20-24	48.8	56.0	73.0	62.8	71.8	71.4	138.2	133.8	117.3
25-29	45.8	53.6	73.0	55.0	57.4	69.6	128.4	122.6	108.8
30-34	44.6	54.4	76.0	57.4	56.0	66.6	121.2	114.4	105.8
35-39	45.2	57.6	75.6	56.0	60.0	65.8	116.7	113.6	103.7

Scenario 4: Opportunity Costs.

This harvest allocation rule directs the harvest to stands where there is imminent danger of having large volumes of wood become unmerchantable.

This allocation rule targets stands with high volumes or rapid rates of volume decline (See Tables 3 and 5) and especially

stands in the first stage of collapse which have both attributes. The opportunity cost is also influenced by the yields expected under different management regimes from future rotations, but in this case their effect is negligible because the long rotation lengths drastically reduce their present net value.

This scenario has the important feature that stands become non-targetted beyond a certain age. This property is counter-balanced by the oldest first allocation of non-target stands, but as more of the MAD is allocated to target stands, there will be a greater likelihood that over-age, non-target stands will be written off.

Table 11 is a comparison of the age ranges of target stands when different minimum opportunity costs are chosen. The range of stand ages which are targeted for harvest tends to expand in both directions as the minimum opportunity cost falls, due to the shape of the opportunity cost by age curve.

Table 11

Effects Of Minimum Opportunity Cost On Age Range Of Target Stands

	Target Stand Age Range When Minimum Opportunity Cost Is:	
Stand Type	$1000/ha	$1150/ha
Upland	125 - 155	130 - 150
Lowland	105 - 160	115 - 160
Jack Pine	95 - 150	100 - 150

The characteristics of the six sample simulations run under this scenario are listed in Table 12 and the summary statistics are displayed in Table 13.

The most striking result is the stability of the road cost per cubic metre of wood. As more of the MAD is taken from designated stands, the greater road expenditures required are counter-balanced by higher harvest volumes per hectare. Consistently low road expenditures per cubic metre of wood result.

As one would expect, the total harvest volume rises when more of the MAD is taken from target stands, but differs little when the minimum opportunity cost is raised from $1000/ha to $1150/ha. The overall percentage of lowland cut is also stable.

The general behaviour of the opportunity cost allocation rule can be deduced from the age-class structure of current forest (Figure 2). The bulk of the current target stands are on lowland sites, which remain in the target range for twenty years. From years 20 to 30, the

Table 12

Descriptions Of Six Opportunity Cost Runs

Run No.	% MAD From Designated Stands	Minimum Opportunity Cost ($/ha)
14	50	1000
15	50	1150
16	60	1000
17	60	1150
18	70	1000
19	70	1150

Table 13

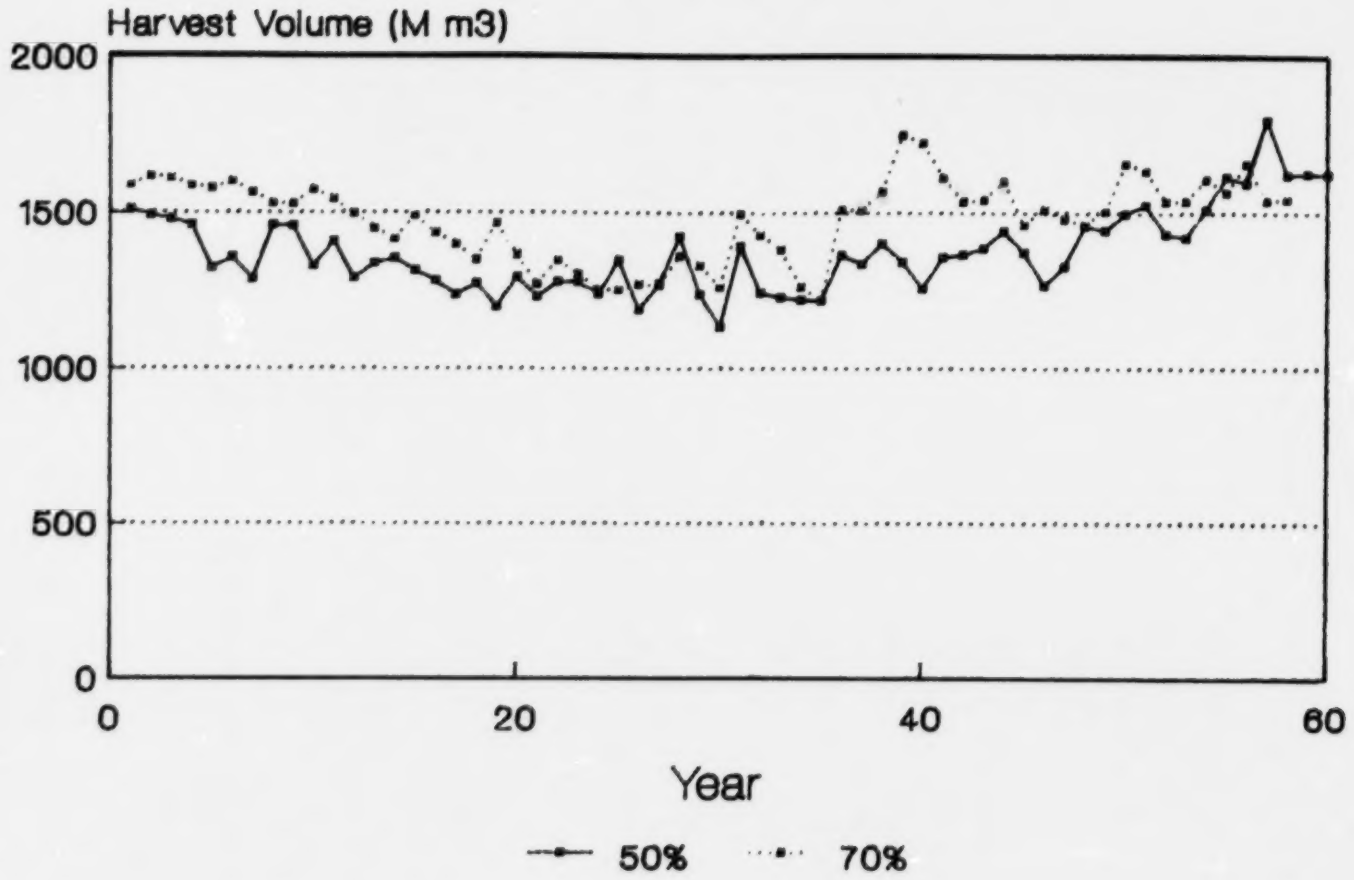
Summary Statistics From Six Opportunity Cost Runs

Run No.	Total Vol. Cut (10^6 m^3)	Vol. Left In Old Forest (10^6 m^3)	Discounted Road Cost Per m^3	Total Discounted Road Costs	Harvest Volume Per ha.	Pct Lowland Area Cut
14	74.1	10.4	1.12	$82.9 X 10^6	129.73	54
15	74.5	13.8	1.11	82.7 X 10^6	131.06	58
16	76.4	11.4	1.09	83.0 X 10^6	134.28	56
17	78.4	13.2	1.14	89.5 X 10^6	138.32	58
18	80.5	9.3	1.11	89.1 X 10^6	141.85	55
19	81.8	11.3	1.18	96.8 X 10^6	144.34	57

140-149 year stands become non-designated while the current 130-139 lowland stands remain designated. During this decade, the bulk of both portions of the MAD will be lowland. The last thirty years the simulation will see both younger stands and upland sites constitute an increasing proportion of the cut.

This pattern can be modified by adjusting the minimum opportunity cost of target stands and the composition of the MAD. However, any modification cannot eliminate the influence of the underlying stand demography. The annual timber harvests, two of which are illustrated in Figure 9, show this. In all cases, harvest volumes decline over the first thirty years as the 130-149 year old lowland stands move through the targeted age classes. Volumes fall as the stands deteriorate. After thirty years, the volumes begin to rise because the bulge of the overmature lowland now affects only the

Figure 9. Annual Harvest Volumes
Min Opp Cost = $1000



non-target part of the MAD. An examination of the types of area cut reveals that no single division of the MAD consistently cuts the most or least lowland area. This differs from the first twenty years of the simulation - then more lowland is cut when target stands constitute a greater percentage of the MAD.

Under the opportunity cost rule, the bulge of over-mature lowland can be hit hard while it remains in the target range (runs #18 and #19) or it can be hit moderately hard at all ages (runs #14 and #15). Thus it is inevitable that a relatively stable percentage of lowland will be cut under different examples of this scenario. However, allocation parameters do affect the ages and volumes of harvested stands. Harvest volumes are higher when a higher percentage of the MAD consists of target stands.

Also, the most consistent average harvest ages are yielded under the 70% MAD runs. This is better from the company's viewpoint, providing a more uniform mill supply and regeneration program.

So far, the effects of cutting different percentages of target stands have been compared. The effects of raising the minimum opportunity cost from $1000/ha to $1150/ha are more straightforward. The range of acceptable stands ages is narrowed by cutting out the lower volume stands. This has the effect of raising the total harvest volume and the average harvest volume per hectare. Road costs increase since there are fewer target stands. Raising the minimum opportunity cost also delays the arrival of the relatively large area of 60-90 year old upland into the specified range and speeds the exit of the 130-149 year old stands. The net effect is a slight rise in the overall percentage of lowland cut.

Comparing The Four Scenarios

The Ministry must balance a number of objectives when selecting a harvest allocation rule and so there will be no objective criterion for identifying an optimal rule. Almost certainly, none of these scenarios in its pure form is the optimal allocation strategy. It is equally likely that if one of these scenarios was used in practice, the Ministry would use different parameters than were used here. Furthermore, the selected policy would certainly be amended before 60 years passed. In light of these considerations, the most fruitful approach is to evaluate the strengths and weaknesses of each allocation rule and weigh the trade-offs.

To recapitulate, the four scenarios were:

1) Oldest First - At least 70% of MAD was taken from stands above 120, 140 and 150 years on the basis of oldest first.

2) Minimum Sufficient Road Extension - The entire MAD came from stands at least 80 years old.

3) Preferred Sites - Various percentages of the MAD were taken from stands which would be regenerated to spruce upland and managed lowland. The remainder came from non-preferred sites on an oldest first basis.

4) Opportunity cost - Various percentages of the MAD were taken from stands in which the opportunity cost of leaving the stand uncut for one year exceeded either $1000/ha or $1150/ha. The remaining wood was cut on an oldest first basis.

The preferred sites case is unique because the percentage of target area in the management unit will not change over time. In contrast, every stand eventually meets the target criteria in the other three harvest scenarios.

In the preferred sites scenario, therefore, throughout one rotation it is difficult for preferred sites to supply a percentage of the MAD larger than the percentage of the unit area that they represent. This latter figure represents an approximate upper limit on the percentage of preferred sites that can be cut each year. It can be exceeded if stands on preferred sites have shorter rotations than other stands; nevertheless, there is only limited room for adjustment. Consequently, if this rule were adopted then the specific features of the harvest allocation rule would have to be set in coordination with preferred site identification. In addition, the full benefits of following this scenario will not be fully appreciated until the regenerated forest reaches rotation age. A sixty-year simulation is too short to incorporate benefits flowing from the nature of the future forest.

The minimum roads and preferred sites options may be called "age-passive" harvest allocation rules because the average age of the harvest cut is entirely dependent on the age-class distribution of the forest. In these scenarios, the average age of the cut rises throughout the first forty-five years of the simulation as the overmature bulge of lowland works its way through older and older age classes. The oldest first rule is moderately "age-passive" - a high minimum harvest age is set but whatever stands happen to be older will be cut. In contrast, only the opportunity cost rule defines a target

range with an upper limit on age. By restricting the harvest to a relatively narrow range of age classes with a specific economic attribute, rather than an age attribute, a measure of control is obtained over the characteristic of the harvest volume.

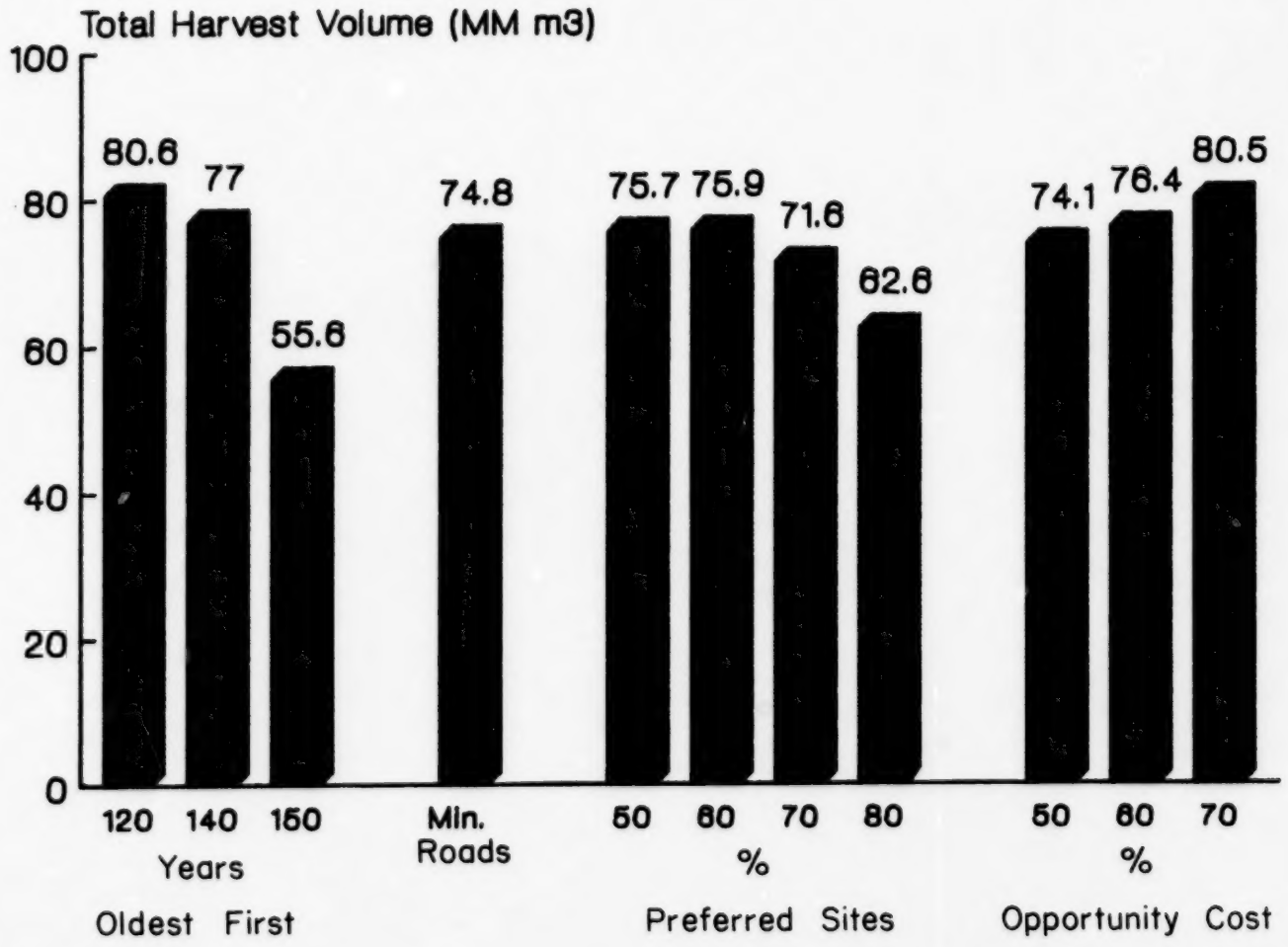
The four most important criteria for judging a cut allocation method would seem to be the total volume cut, the evenness of the harvest volume flow, the discounted road cost per cubic metre, and the condition of the forest at the end of the simulation period.

The total harvest volume is of obvious interest to the company and to the Ministry. Figure 10 is a histogram of the total volume cut during each run. (Opportunity cost runs #14, #16 and #18 are shown.) A larger harvest volume brings more stumpage revenue and creates more value added throughout the economy. At the same time, the characteristics of the wood flow are important. An even (or non-declining) wood flow is an essential prerequisite for stable industrial production and Crown revenues. Planning is easier in a stable environment. The discounted road cost per cubic metre cut reflects the timing of road construction and maintenance activity and the level of harvest. As such, this statistic expresses a relationship between these factors in a way that is relevant to industry and government alike.

By judging the discounted road cost on a per cubic meter of wood cut basis, the efficiency of road-building expenditures is measured in terms of wood output. Since we have assumed that the value of a cubic metre of wood is assumed to be independent of its

FIGURE 10

Total Harvest Volume in each Scenario



age and the number of pieces in it, the road cost per cubic metre is a gauge of the rate of return from road construction and maintenance investments. Of course, roads are built for many other reasons than facilitating timber processing, but often this is their initial use. Figures 11 and 12 are histograms of the total discounted road costs and dsscounted road cost per cubic metre respectively.

The state of the forest after 60 years is also important. No single quantitative measure of its quality is adequate. The volume present is really the only yardstick available to compare differences and it is imperfect for it ignores the age class distribution in the entire each site type. Unfortunately, the data used here is too unreliable and scanty to give an accurate assessment on the quality of the future forest. Also, it is unclear how to judge a forest's quality.

The simulations calculate the MAD on an area allotment basis. If management techniques were to remain unaltered, the forest would be regulated after one rotation. Traditionally, this has been a goal of forest managers. However, in this study lower rotation ages will be administered in the future forest where better and more intensive management is applied. Consequently, the MAD increased throughout the simulation. This effect tended to alleviate the effects of declining harvest volumes per hectare during the simulation. Despite this harvest volumes declined from the present to year thirty. This happened in all scenarios and appears to be unavoidable under the secnarios exanmined here. Forest managers cannot completely free themselves from the underlying demography of the forest. However, managers are not completely imprisoned - they can choose an

FIGURE 11

Total Discounted Road Expenditure in each Scenario

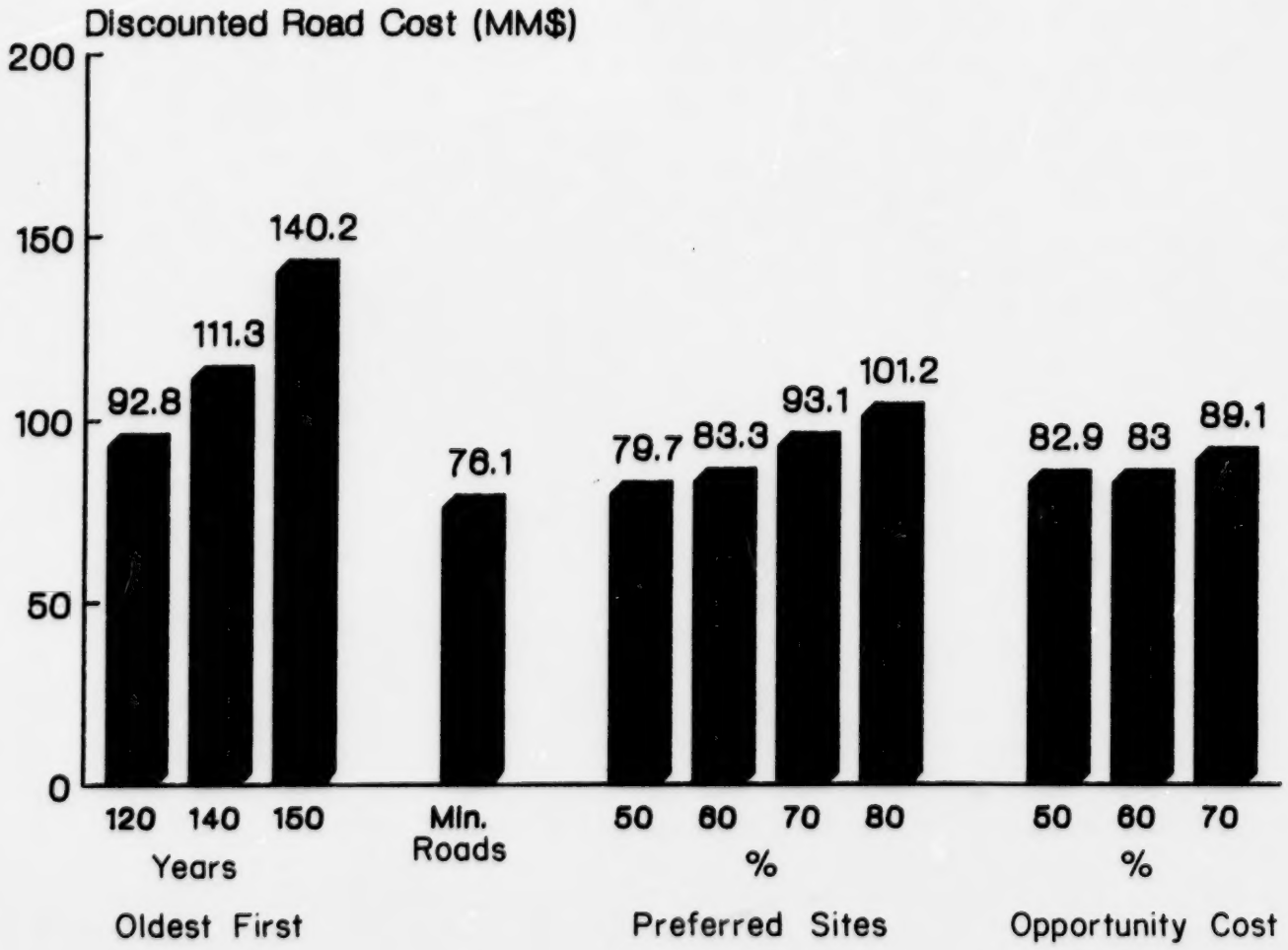
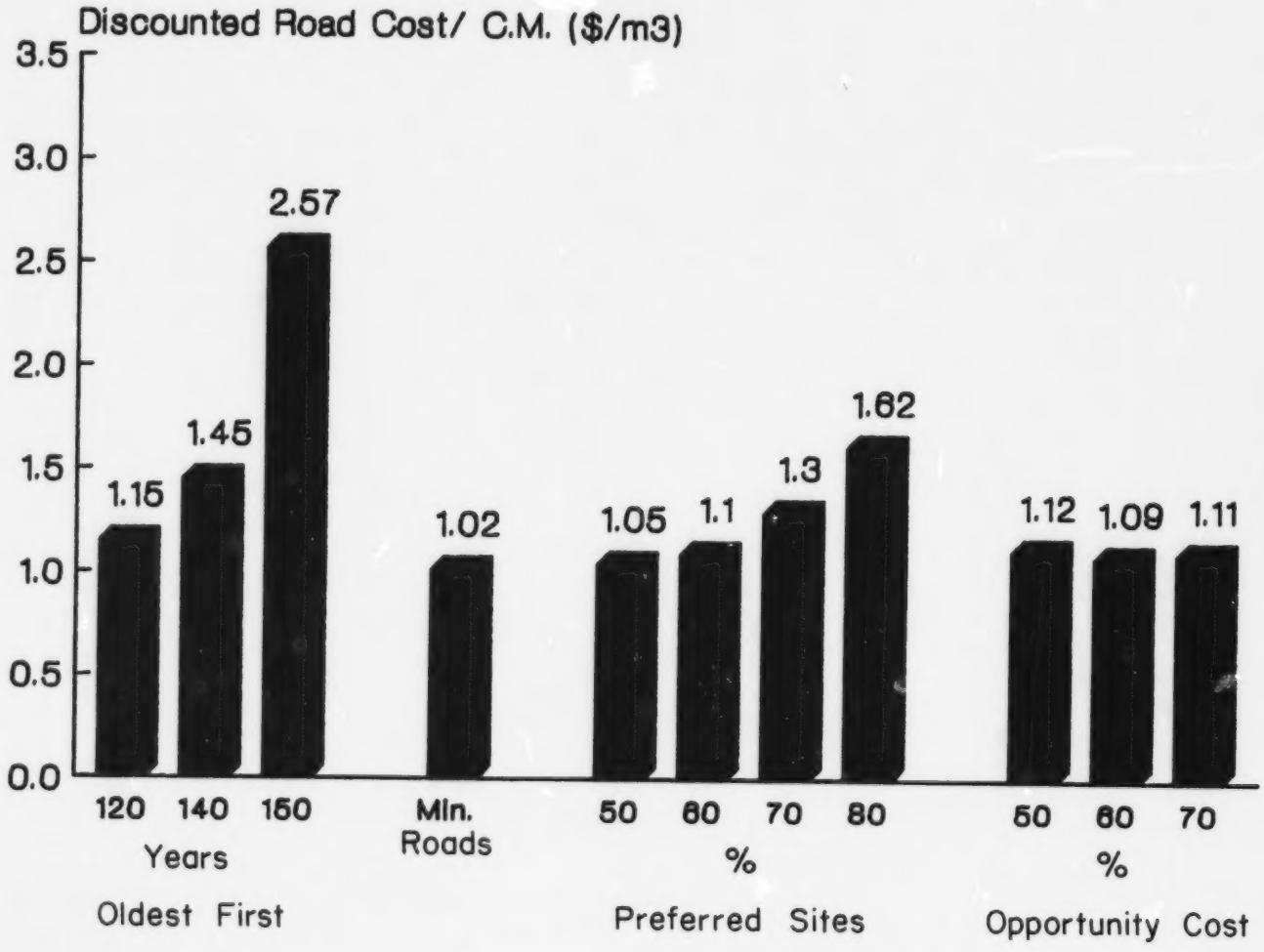


FIGURE 12

Discounted Road Cost/Cubic Meter Harvested in each Scenario



appropriate balance of cutting in overmature and mature forest to mitigate the decline. Some type of area acceleration, increased reliance from out-of-unit wood or increased utilization of stands are possible means of leveling out the annual timber flow.

The total harvest volumes shown in Table 10 are quite stable under the various scenarios illustrated. The total harvest tends to decrease slightly as the oldest first and preferred sites scenarios are followed more stringently, whereas the harvest volume rises somewhat as the opportunity cost scenario is applied more strictly. The two scenarios with significantly lower volumes behaved this in part because the simulations terminated before sixty years had elapsed. A detailed description of each rule's behaviour was given earlier. Despite the similarities in total harvest levels, there were differences in the year-to-year variation of the annual harvest.

The total discounted road costs increase in each scenario as the target stands are chosen more selectively, or as they are required to contribute a larger portion of the MAD. This is a very important result because it demonstrates that more access is required whenever more selective forest management is undertaken. The choice of harvest rule and the biological characteristics of the management unit affect the magnititude of the expenditures, but this basic principle remains valid. Therefore, it is not the oldest first policy per se that has led to higher road outlays, but the move to more selective management.

It is important to discount the series of road expenditures. Choosing a harvest rule affects only the timing of road construction, not total mileage constructed. At the end of each simulation, the entire unit was accessed (although some roads had been abandoned).

However, the timing of cuttings has important financial consequences, since real rates of interest are usually a fact of life.

The minimum roads extension scenario lived up to its name and delivered the least cost road system. One might have expected this secnario to yield results similar to the 50% preferred site case (since 52% of the unit is preferred) and to the 120-year oldest first case (since much of the forest is older than this). The former hypothesis was shown to be largely correct, while the latter was very wrong.

As the oldest first and preferred sites scenarios were applied more intensively, road costs rose and harvest volumes fell slightly. Figure 12 shows that the road cost per cubic metre rose substantially as a result. In contrast, the expanded road program in the opportunity cost scenario also resulted in a stable cost per cubic metre.

The age pasivity of the oldest first and preferred sites rules led to less even annual harvests than under the other two scenarios. The minimum roads and opportunity cost scenarios have built-in stabilization factors. In the case of minimum roads, the wide range of ages and site types that are eligible permits the law of averages to take effect (this is present in the preferred site case to a lesser extent), whereas in the opportunity cost case, it is the stipulation that a certain portion of the cut must come from a limited range of physiological ages.

In closing, the dangers of applying these conclusions wholesale to another management unit must be emphasized The results are dependent on the age class structure and range of site types in

the test management unit and great differences can be expected in other circumstances.

Conclusions

The following conclusions were reached in this study:

1) The biological characteristics, road construction schedule and harvest are inter-related and are affected, directly and indirectly, by the choice of the harvest allocation rule. A policy which affects one of these elements will directly affect the remaining elements.

   The relative performance of the allocation scenarios on this management unit is not a judgement of their intrinsic merit - relative performance will likely differ in another management unit.

2) The important aspect of road-building activity here is the timing of road construction, rather than total mileage built. The entire management unit was accessed at the end of each simulation but the total discounted road cost varied widely because of the road construction schedules varied.

3) Road building activity will accelerate whenever more selective management is applied. When the harvested stands are chosen according to more stringent requirements or when a particular subset of stands is relied upon for an increased percentage of the harvest, then discounted road cost must increase. Hence, it

is not the oldest first rule *per se* that has caused road expenditures to rise above traditional levels, but rather the adoption of a more selective harvest policy that is responsible. An arbitrary limit on road expenditures will restrict available management options.

APPENDIX 1

Data File Specifications

Data File: param.dat

Contains the economic data, the cut parameters, the costs and timing associated with the regeneration program, the age of rotation and free-to-grow, and the number of trees planted/hectare under each regeneration program.

Line No.	Col. No.	Format	Data Description
1	1-5	f5.3	Annual Rate of Interest
1	6-11	f6.2	Value Added/m^3
2	1	i1	Option number if option 1, 2 or 3 is being run. 1 = oldest first 2 = preferred sites 3 = minimum road extension
3	1-3	i3	Minimum permissible harvest age.
4	1-3	i3	If option = 1, the minimum age for old stands
5	1-5	f5.3	For all options but #3, the percentage of the AAC to come from designated stands.
6	1-3	i3	Rotation age of old forest
	4-6	i3	Age of free-to-grow for old forest.
7	1-3	i3	Rotation age for unmanaged upland forest
	4-6	i3	Rotation age for mixed upland forest
	7-9	i3	" " " spruce upland forest
	10-12	i3	" " " unmanaged lowland forest
	13-15	i3	" " " managed lowland forest
	16-18	i3	" " " jack pine forest
8	1-18	6i3	As in line 7, ages of free-to-grow for 6 stand types.
9	1-3	i3	Year of simulation when 1895 burn becomes available for harvest.
	4-6	i3	Year of simulation when 1923 burn becomes available for harvest.
10	1-8	f8.2	Road construction reimbursement rate per kilometer of primary road.
	7-16	f8.2	Road construction reimbursement rate for kilometer of secondary road.
	17-24	f8.2	Road maintenance reimbursement rate per kilometer of road.

	25-29	f5.3	Real rate of road construction reimbursement rate increase per year.
	35-36	fi2	Length of period between time all the timber accessible from primary road is cut and the time when that road will be closed, if it is to be closed.
	37-38	i2	Length of time between year when all timber accessible from a secondary road is cut and the year when that road will be closed.
11	1-3	i3	Years after cut when site is site prepared, for unmanaged upland.
	4-9	f6.2	Cost of site preparation per hectare of unmanaged upland.
	10-15	f6.2	Probability that site preparation is required on unmanaged upland.
	16-30		As in columns 1-15 for planting on unmanaged upland.
	31-45		As in columns 1-15 for the first tending on unmanaged upland.
	46-60		As in columns 1-15 for the second tending on unmanaged upland.
12-16			As in line 11, one line for each of mixed wood, managed upland, unmanaged lowland, managed lowland and jack pine.
17	1-30	6i5	Number of trees planted per hectare of unmanaged upland, mixed wood upland, spruce upland, unmanaged lowland, managed lowland and jack pine.

Data File: yield.dat.

Growth and yield data for each stand type.
Format repeats for each stand type.

Line No.	Col. No	Format	Data Description
1	1-2	i2	Stand type code: 10 = unmanaged upland 20 = unmanaged lowland 11 = mixed wood upland 21 = managed lowland 12 = spruce upland 30 = jack pine
	3-4	i2	Number of 5-year yield and growth data
	5-7	i3	Age of last 5-year yield figure

2	1-5	f5.3	Yield in m^3/ha at year 5.
	6-10	f5.2	Current annual increment in m^3/ha between years 5 and 9.
	11-70		Yield and c.a.i. repeat, presented at 5-year intervals.
	3-7		As on line 2, yield and c.a.i. data at increasingly older ages.

Data File: regen.dat.

A list of regenerating stands created through harvests between 1972 and 1986, from company records.

Line No	Col. No.	Format	Data Description
all	1-8	i8	Stand number
	9-10	i2	Stand type code, as in yield dat.
	11	i1	Stand type code: 1 = unmanaged upland 4 = unmanaged lowland 2 = mixed wood upland 5 = managed lowland 3 = spruce upland 6 = jack pine
	12-16	i5	Area
	17-19	i3	Age

Data File: friwc2.dat.
The updated stand information file. For each stand, its number and access road kilometer number are recorded. This file is sorted. The sorting levels are: road number, the primary level; road kilometer number, the secondary level; and harvest region number, the tertiary level.

Line No.	Col. No.	Format	Data Description
all	1-8	i8	Stand number usually consists of 4 middle digits from township code multiplied by one thousand, plus the F.R.I. stand number. For townships Aitken, Hicks, Griffin, Oke, Ford Powlett, Slade, Stringer and Watson, the number is formed from the middle four digits of the township code followed by the F.R.I. stand number with leading zeros omitted.
	9-10	i2	Stand type code. As in yield. dat.
	11-15	i5	Area of stand in hectares

16-18	i3	Stand age in years
19	i1	Harvest region number of stand
20-22	i3	Number of road which accesses stand
23-24	i2	Distance of new road that must be built to access stand.

This format is repeated for each stand. In addition, lines with a stand number of 9999 are placed at the end of each road. Distance figures equal last distance plus the kilometer. Also, dummy stands with zero area and a distance of one kilometer less than the shortest distance on a road are included if the first kilometer number is above one. Finally, stands on road 99 at distance 99 are written off. This file is sorted by (1) road number (2) distance or kilometer number (3) harvest region.

Data file: roads dat.

Roads data file contains the road number, road grade, constructed length and total length from company records.

Line No.	Col. No.	Format	Data Description
1	1-3	i3	Road number
	4-6	i3	Total length of road (kilometer)
	7-8	i2	Road grade code: 10- permanent primary road; 11-temporary road; 21-secondary road.
	9-11	i3	Length of road already constructed.

This format is repeated once for each road.

APPENDIX II

Operation of the Model

The model used in this study was an adapted version of the OWOSFOP model used by the Ministry to calculate MAD's for FMA's and to simulate a forest's response to future harvesting.

Essentially, OWOSFOP projects the growth of a single working group or an aggregation of working groups. The present forest continues to grow according to the yield curve it is presently following and regenerated stands grow according to a user-specified yield table. The official version of OWOSFOP runs by five-year iterations. However, some companies have taken OWOSFOP and adapted it to their own needs and likely have other capabilities. In any event, the general principles used in these simulations are well-known and well-accepted throughout the forestry community in Ontario.

Two adaptations of OWOSFOP were developed for this study: one to run the first three options - oldest first, minimum roads and preferred sites - and a second for the opportunity cost scenario. Both models are similar. Each runs on a stand-by-stand basis and records the location of each stand. An annual iteration period was used.

When run, they first read the five input data files and print scenarios of them. (The technical specifications and formats of these files are listed in Appendix 1.) If the three-option model is being run, the user chooses the appropriate scenario to run; otherwise the opportunity cost scenario will be simulated. When the preferred sites

option is selected, the equivalent annuities obtained under each management program are displayed on the terminal and the user enters the minimum annuity value which would be acceptable from a preferred site. When the opportunity cost model is run, the user is asked to select the opportunity cost which separates target stands from non-target ones. For each stand type, the terminal displays the range of stand ages that will be targetted for harvest.

As the next step, the model calculates the MAD. The program doesn't distinguish stand working groups and so, for the purposes of determining the MAD, the whole forest is treated as a single working group with a 110-year rotation and an 18-year free-to-grow period. This differs from current practice, whereby hardwood stands are managed on a 70 to 75-year rotation with a 5-year free-to-grow period. However, the MAD calculated by the model is only 6 per cent lower than the one used in practice.

Once the MAD is calculated, the program orders the stands by age, harvest region priority, and distance to the nearest completed road. Using the selected harvest allocation rule, the program can now identify the stands to be cut in the current iteration and proceeds to make the required harvest. The attributes of uncut stands are updated and the cutover is distributed in a regeneration file according to stand type. The location of individual stands is lost once they are cut.

The simulation period is 60 years; the MAD is updated every five years or when a new harvest region becomes eligible. Harvesting activities move into a new cutting region when there is insufficient

eligible area for the MAD within 10 kilometers of the current roads. If the proportion of stands eligible for harvest is too small, then there will not be enough suitable area to provide the MAD for 60 years. The program stops whenever the MAD cannot be filled. Whenever the program ends, the model summarizes the harvest, silvicultural, and road building statistics and calculates the availability of timber from the new forest.

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ISSN 0228-5754
ISBN 0-7729-3072-4

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Printed in Ontario, Canada

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Cover:
A map illustrating the southern portion of the Gordon Cosens Forest (part of the Spruce Falls Pulp and Paper Co. Ltd. FMA). The dotted lines indicate existing resource-access roads.